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Investigations of the Biological Consequences and Cultural Motivations of Artificial Cranial Modification Among Northern Chilean Populations

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A thesis submitted in partial fulfillment of the requirements for the degree in Doctor of Philosophy

Investigations of the Biological Consequences and Cultural Motivations of Artificial Cranial Modification Among Northern Chilean Populations
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Abstract

The purpose of this study is to build on existing normative models of craniofacial growth and previous craniofacial studies of artificial cranial modification (ACM) in order to deepen the cultural and biological understanding of the this practice. Areas of concentration include a study of the biological changes to cranial epigenetic traits and facial metrics related to ACM, an examination of the biological effects of ACM in order to assess their implications on morbidity and mortality, and an investigation into the cultural motivations for ACM. Three hypotheses were tested: 1) ACM did not affect epigenetic trait incidence or facial metrics; 2) ACM increased morbidity and mortality of modified individuals; and 3) ACM was a marker of either social status or ethnicity. These hypotheses were addressed using quantitative and qualitative analyses of the craniofacial skeleton of ancient northern Chilean groups, including cephalometrics, craniometrics, various statistical analyses, and survey of specific epigenetic traits, pathological conditions, and grave goods. As well, these hypotheses were also addressed using various ACM typologies placed within the context of a "nested typology". It was concluded that when ACM styles are pooled the effects of ACM are not discernable, but the results did demonstrate that the various ACM styles do affect epigenetic traits and some facial metrics. ACM did minimally affect morbidity and mortality within these samples. As well, ACM was not practiced solely as a marker of social status or ethnicity, and it was ultimately determined that motivations for practicing ACM were multifactorial.

Keywords

Artificial cranial modification, Azapa Valley, Lluta Valley, Camarones Valley, cephalometry, epigenetic traits, status, ethnicity, Chile

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Chapter 1

1 Introduction

The purpose of this doctoral research is to build on existing normative models of craniofacial growth and previous craniofacial studies of artificial cranial modification (ACM) in order to deepen the cultural and biological understanding of this practice. Three separate but methodologically related investigations were undertaken in order to explore three principle goals: 1) to ascertain if, and to what extent, ACM among northern Chilean groups affected epigenetic trait incidences and facial measurements, 2) to establish if ACM led to increased morbidity and mortality amongst modified individuals, particularly infants and children, and 3) to determine the social motivation(s) (status, ethnicity, or other) for conducting ACM in past northern Chilean populations. These objectives were investigated with complimentary quantitative and qualitative methodologies of the craniofacial skeleton, placed within the contexts of an individual's skeletal health. The results of this study will clarify existing debates regarding to biological affinity studies on northern Chilean groups, further our general knowledge about the practice of ACM, specifically within Andean contexts, and advance the current understanding of the existing cultural history models of ancient northern Chile.

1.1 Literature Review: Artificial Cranial Modification

Artificial cranial modification (ACM) is defined as the manipulation of the cranium through the application of an external appliance in order to alter the natural form of the skull (Anton and Weinstein, 1999; Gerszten, 1993; Perez, 2007). It was practiced by many different groups of varying social complexity (from hunter-gatherers to state-level societies) all around the world (Allison *et al,* 1981; Cocilovo *et al*, 1982; Dingwall, 1931; Munizaga, 1976). A variety of modification styles have been identified, many of which are associated with different cultural groups world wide (e.g. annular and fronto-occipital modifications) (Allison *et al.*, 1981; Dembo and Imbelloni, 1938; Dingwall, 1931; Hrdlička, 1912; Neumann, 1942; Weiss, 1961). The cultural motivations for practicing

ACM are numerous but the most common include its use as a natural aesthetic enhancer, for the instillation of specific personality characteristics, protection against evil spirits, and the identification of either individual (e.g. social status/rank) or group (e.g. ethnic) identity (Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; de la Vega, 1966 [1609]; de las Casas, 1982 [1561]; Dingwall, 1931; Julien, 1993; Morton, 1839; Torquemada, 1995 [1557-1664]; Stewart, 1943; Weiss, 1961).

While practiced to varying degrees world wide, ACM was common in pre-contact South America, particularly in northern Chile (Arriaza *et al.*, 2008; Virchow, 1892). The earliest incidences of ACM were reported from the Archaic Period (8000 to 1500 B.C.) and this practice continued until the Spanish conquest in the 16th century (Arriaza *et al.*, 2008; Dingwall, 1931; Morton, 1839). Several different modification styles have been identified in various South American areas (cf. Allison *et al.*, 1981; Dembo and Imbelloni, 1938; Hoshower *et al.*, 1998; Munizaga, 1976; Weiss, 1961). Despite the existence of numerous ACM styles, scholars have noted specific stylistic trends with particular styles clustering in specific geographical regions (e.g. coastal groups tended to practice fronto-occipital modification and highland groups tended to practice annular modification) (Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; de la Vega, 1966 [1609]).

Many biological changes and pathological responses have been attributed to ACM, but several of these are not agreed upon or are imprecisely known. Previous studies agree that a degree of cranial morphological change is produced, but the amounts and locations of these changes differ even if modification styles and the devices used to create the styles are similar (Anton, 1989; Bjork and Bjork, 1964; Cheverud *et al.*, 1992; Frieß and Baylac, 2003; Kohn *et al.*, 1993 & 1995; McGibbon, 1912; McNeill and Newton, 1965; Moss, 1958; Oetteking, 1924; Schendel *et al*., 1980). This has led to several different debates in the literature, particularly concerning morphological changes to the face. Some scholars have concluded that ACM does change facial dimensions (Anton, 1989; Anton and Weinstein, 1999; Bjork and Bjork, 1964; Brown, 1981; Cheverud *et al.*, 1992; Cybulski, 1973; Hrdlička, 1914; Kohn *et al.*, 1993; Manriquez *et al.*, 2006; Oetteking, 1930; Pomeroy *et al.*, 2010; Rhode and Arriaza, 2006; Schendel *et al.*, 1980), while others have disagreed with this conclusion (Blackwood and Danby, 1955; Cocilovo, 1975; Ewing, 1950; Frieß and Bayloc, 2003; Kohn *et al.*, 1995; Ross and Ubelaker, 2009; Rothhammer *et al*., 1982; Verano, 1987). This area of change remains hotly debated and requires further investigation since certain methods (e.g. biodistance analyses) rely on facial dimensions and would be deemed unreliable if facial dimensions are greatly affected (Cocilovo, 1975).

ACM may also affect the development and incidences of epigenetic traits. Several studies have investigated this matter but have reached different conclusions. Some studies concluded that ACM changes the frequencies of epigenetic traits (Cilento, 1921; del Papa and Perez, 2007; Dorsey, 1897; El-Najjar and Dawson, 1977; Gerszten, 1993; Gottleib, 1978; Guillen, 1992; McGibbon, 1912; Oetteking, 1930; O'Loughlin, 2004; Ossenberg, 1970; Sanchez-Lara *et al.*, 2007; van Arsdale and Clark, 2011; White, 1996), while others found no significant change (Anton *et al.*, 1992; Anton and Weinstein, 1999; Dingwall, 1931; Konigsberg *et al.*, 1993; O'Loughlin, 2004; Wilczak and Ousley, 2009). A resolution to this debate has been difficult to come by since some scholars believe that epigenetic traits are under strict genetic control and minimally affected by environmental conditions (e.g. ACM) (Konigsberg *et al.*, 1993), while others have presented evidence that shows that environmental factors can significantly impact epigenetic trait frequencies (Adis-Castro and Neumann, 1948; Anton *et al*., 1992; Bennett, 1965; del Papa and Perez, 2007; Dorsey, 1897; El Najjar and Dawson, 1977; Gerszten, 1993; Gottlieb, 1978; Guillen, 1992; Hrdlička, 1935; Montague, 1937; O'Loughlin, 2004; Ossenberg, 1970; Sanchez-Lara *et al*., 2007; van Arsdale and Clark, 2010; White, 1996). No definitive conclusion regarding how ACM affects epigenetic trait incidences and frequencies has yet been presented in the literature. This disagreement affects the accuracy of biological distance analyses that utilize epigenetic traits as a means of determining biological similarities and differences amongst groups since the ACM related effects on these traits are imprecisely known and cannot be properly controlled for when these methods are utilized.

There are other biological changes and pathological conditions noted in modified crania. These include the premature fusion of cranial sutures (Gerszten, 1993; Gerszten and

Gerszten, 1995; Holliday, 1993; White, 1996), increased incidences of sagittal keeling (Anton and Weinstein, 1999; O'Loughlin, 2004), endocranial shape changes (e.g. organization and orientation of blood vessels, sinuses, etc.) (Dean, 1995; MacLellan, 2006; O'Loughlin, 1996), and bone necrosis (Gerszten, 1993; Gerszten and Gerszten, 1995; Holliday, 1993). Some of these changes have been associated with the premature deaths of several infants (Diez de San Miguel, 1964 [1567]; Guillen *et al.*, 2009; Mendoca de Souza *et al.*, 2008), but it is unclear if these were isolated or commonplace incidences.

1.2 Outline of Doctoral Research

The objective of this dissertation is to explore the debates outlined here regarding the effects of ACM on facial metrics and epigenetic traits, the connection to morbidity and mortality, and the social motivations and of ACM among northern Chilean populations and by extension within the broader Andean region. Resolutions to these debates will increase our understanding of ACM within Andean contexts, clarify the cultural history of northern Chile, and explain if and how ACM relates to morbidity and mortality. This doctoral research will approach these debates by focusing on three different research themes: ACM and facial metrics and epigenetic traits, ACM and morbidity and mortality, and ACM and its social motivations.

1.3 Artificial Cranial Modification & Cranial Morphological Change

While it is obvious that ACM does produce some sort of morphological change to the cranium, it remains unclear where and to what extent these changes occur, particularly regarding morphological changes to the face and epigenetic traits of the skull. The extent of these debates was previously mentioned in this chapter and is further described in subsequent chapters (see Chapters 2 and 3). It is important to resolve these debates since these cranial characteristics are often used in biological affinity studies to determine genetic relatedness within and among groups. Both of these characteristics have been widely used to determine biological affinities among northern Chilean groups (Guillen, 1992; Rothhammer *et al.*, 1982, 1983, 1984; Rothhammer and Santoro, 2001; Rothhammer and Silva, 1990; Sutter and Mertz, 2004; Varela and Cocilovo, 2002). Many of these studies, however, did not sufficiently address the effects of ACM on their results, requiring further study into the effects of ACM among these populations in order to test the utility of these studies.

1.3.1 Hypothesis Testing

The first purpose of this doctoral research is to determine the effects of ACM on facial dimensions and epigenetic traits, which will be tested through two different hypotheses. The first hypothesis is that ACM does not affect facial dimensions. If this hypothesis is supported, then these studies can be accepted as is and the methods can continue to be used, but if this hypothesis is rejected, this will call into question many of the studies on northern Chilean groups that used facial metrics to assess biological affinity. This hypothesis will be tested through cephalometric analyses, which will look for areas of facial changes among modified and unmodified individuals. The hypothesis would be supported if there were no facial changes observed between the modified and unmodified individuals, and the hypothesis would be rejected if there were significant facial measurement differences noted between the two groups.

The second hypothesis is that ACM does not affect the incidences of epigenetic traits. If this hypothesis is supported, then this method can continue to be used and the studies of biological relationships utilizing these traits cannot be automatically rejected. If, however, this hypothesis is rejected, these methods may not be used among these groups without modifications to the methods and the studies called into question. This hypothesis is tested by observing epigenetic trait incidence among modified and unmodified individuals and assessing these differences through the Mean Measure of Divergence (or Distance) (MMD) analysis. The hypothesis would be supported by a lack of epigenetic trait difference between modified and unmodified individuals, whereas the hypothesis would be rejected if a difference did exist, be it an increase in traits among either modified or unmodified individuals.

1.4 Artificial Cranial Modification & Morbidity and Mortality

It is generally believed that ACM had little to no impact on morbidity and mortality because if it did, the practice would have been quickly discontinued (Gerszten, 1993). There is, however, historical precedence for societies performing culturally driven changes to the body despite the existence of risks. Women in Victorian England rejected calls to discontinue tightlacing (corsetry) practices despite the known risks to the practioners' health because they viewed the practice as being essential to their femininity (Steele, 2001). Men in Imperial China sought out women with bound feet as they believed the scents associated with the putrification of the foot created greater pleasure during sex (Hong, 1997). There are countless other examples both in antiquity and today of people disregarding the health consequences of body modification in order to convey some sort of identity or meaning (Atkinson, 2003; Brain, 1979; Sanders and Vail, 2008; Sullivan, 2001). The social motivation underlying these and other similar practices must be extremely powerful for them to continue despite the physical costs.

1.4.1 Hypothesis Testing

The ethnohistoric accounts and more recent studies of ACM suggest there were several pathological conditions associated with ACM, including bulging eyes (Diez de San Miguel, 1964 [1567]; Dingwall, 1931); blindness (Dingwall, 1931); diminished sense of smell (Dingwall, 1931); headaches (Dingwall, 1931); ringing in the ears (Diez de San Miguel, 1964 [1567]; Dingwall, 1931); premature suture fusion of the cranial sutures

(Allison *et al.*, 1981; Gerszten, 1993; Gerszten and Gerszten, 1995; Holliday, 1993; Posnansky, 1957; White, 1996); sagittal keeling (Anton and Weinstein, 1999; O'Loughlin, 2004); endocranial shape changes (Dean, 1995; MacLellan, 2006; O'Loughlin, 1996), bone necrosis (Allison *et al.*, 1981; Broca, 1879, cited in Guillen, 1992; Gerszten, 1993; Gerszten and Gerszten, 1995; Guillen, 1992; Holliday, 1993), and premature death (Diez de San Miguel, 1964 [1567]; Guillen *et al.*, 2009; Mendoca de Souza *et al.*, 2008). The second purpose of this study is to investigate the biological changes and pathological consequences of ACM within northern Chilean populations in order to test the hypothesis that ACM affected health on a large scale, herein referred to as the morbidity and mortality hypothesis. If ACM increased mortality on a detectable scale, this could help clarify the various pathological conditions and their causal factors associated with northern Chilean groups. If the hypothesis is rejected, it could mean previous studies presented isolated cases of ACM related deaths or the deaths were not related to ACM as previously proposed.

The morbidity and mortality hypothesis was tested through the assessment of observable osteological morphological and pathological changes that are said to be associated with ACM. These pathological conditions included but were not limited to sagittal synostosis, premature fusion of cranial sutures, and porotic hyperostosis/bone necrosis. Incidences of these lesions were compared between modified and unmodified individuals in order to assess their relationship to ACM versus their being caused by other diseases, such as scurvy, anemia, or infection. Since these lesions can also be associated with other diseases, they will be evaluated in conjunction with other markers of stress (e.g. dental enamel hypoplasia, cribra orbitalia). These additional markers of stress can be used to determine if the ACM-related lesions were the product of growth changes from ACM or other pathological conditions. As well, trends in the data will also be observed in order to determine if a particular ACM style or several styles were associated with increased morbidity and mortality versus the remaining styles. The morbidity and mortality hypothesis is further tested by observing the number of deceased modified versus unmodified individuals both among juveniles only and adults only samples.

The morbidity and mortality hypothesis would be supported if the incidences of these biological changes and pathological lesions were consistently present and at high incidences among the modified versus unmodified crania, and if the proportion of deceased modified individuals was greater than the unmodified individuals. The hypothesis would be rejected if there were no discernable differences in the incidences of the biological changes and pathological lesions between modified and unmodified individuals, and there was no difference in proportion of modified and unmodified deceased individuals within the sample.

1.5 Artificial Cranial Modification & Social Motivations

Currently there exists an unresolved debate regarding the interpretation of the ethnohistoric record and bioarchaeological studies regarding the cultural motivation for the practice of ACM in South America. Some ethnohistorians and scholars believe ACM was a marker of ethnicity (Blom *et al.*, 1998; Blom, 2005a & 2005b; Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; de la Vega, 1966 [1609]; Dingwall, 1931; Hoshower *et al.*, 1995; Hrdlička, 1912; Stewart, 1943; Torres-Rouff, 2002, 2003, 2009; von Tschudi, 1846; Weiss, 1961), while others believe it was a marker of rank or social status (Boadas-Rivas, 1995; Cassman, 1997 & 2000; de las Casas, 1892 [1561]; Doutriaux, 2004; Sutter, 2005; Torquemada, 1995 [1557-1664]). This debate is particularly relevant to ancient northern Chilean groups since none of the ethnohistoric accounts of ACM are based on evidence from northern Chilean populations, while much of the bioarchaeological evidence in support of ACM as a marker of social status was derived from these groups (cf. Cassman, 1997 & 2000; Sutter, 2005). The third purpose of this dissertation is to test the hypothesis that ACM among northern Chilean groups was a marker of social status, not ethnicity. If this hypothesis cannot be rejected, this calls into question the common assumption among scholars working in the broader Andean area that ACM was a widespread marker of ethnicity. This conclusion could also challenge the culture history models of northern Chilean groups, which is predicated on ethnic divisions. If the hypothesis is rejected, then the prevailing opinion presented in the ethnohistoric literature and current culture history models of the area would continue to be supported.

1.5.1 Artificial Cranial Modification and Ethnicity

A person's ethnicity, or ethnic identity, is based on several criteria, including common biological, cultural, linguistic, ideological, historical, and national traits (Banks, 1996; Eriksen, 1993; Geertz, 1963; Hutchinson and Smith, 1996; Jones, 1997; Weber, 1978). It can be visually represented through a group's material culture, common biological appearance, or modifications to the body (e.g. Aldenderfer and Stanish, 1993; Blom, 2005b; Blom *et al.*, 1998; Cassman, 1997 & 2000; Hoshower *et al.*, 1995; Jones, 1997; Oakland Rodman, 1992; Sutter, 2005). These markers of ethnicity are powerful representations used to define, control, and maintain group identity both within and outside of the group (Barth, 1969). While it is impossible for archaeologists to pinpoint the mechanisms of ethnic identity maintenance, the physical representations believed to reflect ethnicity, such as ACM, can be used to identify ethnic groups, as previously proposed in other Andean bioarchaeological studies (e.g. Blom, 1999 & 2005b, in the Moquegua Valley and Tiwankau; Torres-Rouff, 2002 & 2003, in San Pedro de Atacama).

Deborah Blom (1999 & 2005b) developed a model to identify ACM as a marker of ethnic identity. Based on Blom's model, ACM is a marker of ethnic identity which differentiates geographically separated ethnic groups. She based this model on the identification of ACM stylistic differences between highland and lowland groups, with the former practicing annular modification and the latter fronto-occipital modification. These stylistic differences between these two geographically and ethnically distinct groups were Blom's evidence that ACM was a marker of ethnic identity versus a different type of identity (e.g. social status).

1.5.2 Artificial Cranial Modification and Social Status

Previous studies of ACM from northern Chile, however, do not support Blom or Torres-Rouff's models of ACM as an ethnic identity marker (Cassman, 1997 & 2000; Sutter, 2005). Studies by Cassman (1997 & 2000) and Sutter (2005) used multiple lines of evidence (e.g. textiles and epigenetic traits in conjunction with ACM types) to test the hypothesis that ethnic enclaves existed in the region, but neither Cassman nor Sutter could find evidence in support of the existence of any such enclaves. They further concluded that the results supported ACM as a marker of ascribed status, another motivation recorded in the ethnohistoric accounts (de las Casas, 1892 [1561]). Another study on ancient Columbian groups from the 13th century by Boadas-Rivas (1995) also did not fully support the models developed by Blom. Boadas-Rivas (1995) and Doutriaux (2004) found that ACM was a marker of only social status among the groups they surveyed.

1.5.3 Hypothesis Testing

The last set of studies is in conflict with the ACM as an ethnic identity marker model and encourages further analysis of ACM, particularly within northern Chilean contexts. Two means of testing the hypotheses ACM as a marker of ethnicity and ACM as a marker of social status were undertaken. The first involved an examination of grave good quantity and quality (as based on energy expenditures) between modified and unmodified crania. It was hypothesized that if ACM was a marker of social status that modified crania would consistently be found with more grave goods and higher status grave goods. This method was utilized for only one period, the Regional Development Period data, as this was the only period with data available for testing. The second tested the ACM as a marker of ethnicity hypothesis through an examination of the location (by region and site) of ACM styles in multiple cultural periods among three northern Chilean valleys. It is believed, following Blom (1999 & 2005b) that specific ACM styles should concentrate within geographical areas (in this case, coast or inland valley settlements) and remain constant over time if ACM was a marker of ethnicity.

1.6 Format of Dissertation

This dissertation is presented in the Integrated Article Format, and a total of one literature review chapter and three articles present the investigations accomplished in this study. The first literature review, “Literature Review of Artificial Cranial Modification & Nested Typology,” reviews the previous ACM studies in order to determine what factor(s) led to their differing conclusions. As well, this article explains why a nested typology as derived within the scope of this study is necessary to control for the assessment of some of those confounding factors and to allow for ease of comparison with past and future studies. The first article, “Examining the Effects of Artificial Cranial Modification on Craniofacial Epigenetic Traits and Facial Metrics” is meant to investigate existing debates about the effects of ACM on biological distance analyses, particularly facial craniometric and epigenetic trait methods. This investigation was completed through the use of cephalometric analyses to study facial metrics and MMD analysis to study epigenetic trait incidences between modified and unmodified crania. The second article, “Love You to Death: An Investigation of Artificial Cranial Modification, Morbidity, and Mortality,” examines previous studies concentrating on the biological changes and pathological conditions associated with ACM. ACM styles among northern Chilean adults and juveniles were compared to incidences of ACM-related pathological conditions and biological changes in order to test the hypothesis concerning ACM and increased morbidity and mortality. The third article, “Identity Crisis: A Reanalysis of the Social Motivations of Artificial Cranial Modification among Northern Chilean Populations,” explores existing ethnohistoric debates about the cultural motivations of ACM, particularly in northern Chilean populations. Modification styles were compared against grave good quantity and quality as well as grave locations in order to test the hypotheses that ACM is a marker of ethnic identity or social status.

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Chapter 2

2 Literature of Review of Cranial Modification and Nested Typology

Artificial cranial modification (ACM) is the manipulation of the cranial vault through the use of externally applied forces in order to change the natural form of the skull (Anton & Weinstein, 1999; Gerszten, 1993; Perez, 2007). Two primary types have been identified: intentional and unintentional modification. Intentional modification is the purposeful act of modifying the cranium, whereas unintentional modification is the accidental reshaping of the skull or changes due to genetics, health, hormones, nutrition, accidents, or sleeping posture (Dingwall, 1931; Flowers, 1881; Gerszten, 1993; Gerszten and Gerszten, 1995; Rogers, 1975).

ACM was practiced by many groups of varying social complexity (Allison *et al,* 1981; Cocilovo *et al*, 1982; Dingwall, 1931; Munizaga, 1976). ACM is found among groups on each habitable continent, although the distribution of this practice varied geographically (Dingwall, 1931). Some scholars claim that the earliest incidence of ACM is associated with a Neanderthal population found at Shanidar Cave (Anton and Weinstein, 1999; Dingwall, 1931; Trinkaus, 1982), and it continues in rare cases among modern groups (FitzSimmons *et al.*, 1998; Molleson and Campbell, 1995).

ACM practices varied around the world, although the only common element among all the practicing groups is that ACM began shortly after birth, when the skull was most plastic and malleable (Blackwood and Danby, 1955; Dingwall, 1931). At this time, the cranium was wrapped, bound, and/or affixed to the preferred deformation device, including but not limited to stones, boards, leaves, reeds, textiles, caps, ropes, cradles, and hands (Barnett, 1955; Cieza de Leon, 1984 [1553]; de la Vega, 1966 [1609]; Diez de San Miguel, 1964 [1567]; Dingwall, 1931; de Landa, 1975 [1524-1579]; Morton, 1839; Weiss, 1961). These devices were most often placed on the cranium by the mother, close female relative, or midwife (Dingwall, 1931), and were often times associated with a specific ritualized component such as cleaning the body or cleansing the soul or spirit (Blackwood and Danby, 1955; Boas, 1921; Dingwall, 1931). ACM devices were subsequently removed at variable times, all dependent on cultural preferences. The total time frame ranged from one year to five years (Boas, 1921; Cieza de Leon, 1984 [1553]; de la Vega, 1966 [1609]; Diez de San Miguel, 1964 [1567]; Dingwall, 1931; de Landa, 1975 [1524-1579]; Morton, 1839; Torquemada, 1995; Weiss, 1961). There are reports of ACM devices being left on until an individual reached adolescence among some European groups (Brain, 1979; Dingwall, 1931). The produced ACM styles are believed to have been strictly controlled by the group (von Tschudi, 1846), although overlap in ACM styles exists across the globe.

ACM has been widely studied for over a century. Scholars have focused on four broad areas of research, including determining the cultural motivations of ACM, ACM-related growth changes, pathological consequences, and typological designations of ACM styles. The purpose of this chapter is to present a comprehensive review of the literature as it concerns these four areas of research, as well as to examine the reasons for discrepancies in results in the literature and present possible solutions to avoid this problem in future research.

2.1 Cultural Motivations of Artificial Cranial Modification

As previously noted, ACM was a world-wide practice and the following section will examine ACM and the cultural motivations that drove this practice by continental region, starting with Europe. ACM was commonplace among European groups, particularly throughout the central continent but is almost nonexistent among historic groups of the United Kingdom (Brain, 1979; Coon, 1965; Dingwall, 1931). The earliest incidence of ACM among European groups is found among Greek and Roman populations (Dingwall, 1931), and the practice continued in mainstream societies as late as World War II (Brain, 1979). Both intentional and unintentional ACM is found on the continent, but intentional modification practices were driven by the societies' needs to convey status differences

(Brain, 1979; Dingwall, 1931), satiate their belief in increasing cranial capacities for the purpose of ensuring memory storage (Brain, 1979; Dingwall, 1931), and in the case of Nazi occupied Europe, fears that their children would not resemble the preferred "master race" outlined by Adolph Hitler (Brain, 1979).

ACM was also a widespread practice among Asian groups (Dingwall, 1931). All types of societies, ranging in complexity from hunter-gatherers to state level societies, practiced ACM but for a variety of reasons (Dingwall, 1931; Torres-Rouff and Yablonsky, 2005; Yablonsky, 1999, cited in Torres-Rouff and Yablonsky, 2005). ACM was reportedly used to increase the appearance of ferocity among the Huns (Brain, 1979; Dingwall, 1931; Retzius, 1895, cited in Schjiman, 2005), but among these and close geographical groups, it evolved into a marker of ethnicity (Yablonsky, 1999, cited in Torres-Rouff and Yablonsky, 2005). Among Indian groups, ACM, along with various other body modifications, was conducted in order to increase the good fortune and luck of the affected (Dingwall, 1931), but it may have also been performed in order to stress differences related to the strict caste system (Brain, 1979).

The next region where ACM was prevalent is Oceania, which includes the islands of southeast Asia, New Zealand, and Australia. ACM practices among these groups began in antiquity and continued into the 20th century (Blackwood and Danby, 1955; Dingwall, 1931). ACM styles varied by region within this area, suggesting that ethnic differentiation may have been a factor in practicing ACM. The primary motivation for this practice that is identified is that ACM served as a means of enhancing the natural aesthetic of the body (Blackwood and Danby, 1955; Delisle, 1880, cited in Schijman, 2005; Dingwall, 1931).

ACM was a regular occurrence among northern African groups but was less frequent among Middle Eastern and southern African groups (Brain, 1979; Dingwall, 1931). The only country in northern Africa that is the exception is Egypt, where the only evidence of ACM is found in sculptures, paintings, and stone reliefs of the Pharaoh Akhenaten, his family, and servants who are depicted with long, oval shaped heads (Dingwall, 1931).

Dingwall (1931) believes that ACM may have been prevalent during the reign of Akhenaten as a means of the people to mimic what was potentially a pathological change in the natural form of his cranium, but there is no other physical evidence or reports in the literature that support this suggestion. The evidence of ACM among northern African groups, however, is more substantial since ethnographic reports support the presence and popularity of this practice, which was carried out as a mean of signifying elite status and ethnicity, as well as increasing the utility of women's heads for the purpose of carrying heavy burdens (Brain, 1979; Dingwall, 1931).

ACM was also widely practiced in North America, so much so that ACM practices vary among four regions: the Northwest Coast/Artic, the American Southwest, the American Southeast, and the Northeast (including groups within the US and Canada) (Boas, 1891; Catlin, 1876; Dennis and Dennis, 1940; Dingwall, 1931; Hrdlička, 1935; Neumann, 1942). The motivations for ACM varied greatly and some of these motivations are currently debated. For example, among groups of the Northwest Coast, ACM is attributed as a marker of social status by Hill-Tout (1907), but Boas (1921) and Cybulski (1973) claim that ACM was primarily a marker of ethnic identity. Hill-Tout (1907) identifies differences in ACM form expression as support for his assertion of ACM as a marker of social status, while Cybulski (1973) supports Boas's (1921) original assertion of ACM as a marker of ethnicity, claiming that the variations in expression is instead a result of differential growth processes. Additional motivations for ACM among North American groups include ACM as an aesthetics enhancer (Boas, 1891; Dingwall, 1931), and ACM as a means of increasing health and strength (Dingwall, 1931).

Among Central American groups, ACM was extensively practiced among pre-Hispanic groups, but the practice was banned when the Spanish conquered these groups (de Landa, 1975 [1524-1579]; Dingwall, 1931). ACM was practiced throughout the continent, from Mexico to Panama, in all types of societies (Dingwall, 1931). The motivations for the practice varied with most evidence coming from ancient Maya groups. These groups claim to have practiced ACM as dictated by the gods as a means to increase intelligence and beauty (de Landa, 1975 [1524-1579]; Dingwall, 1931), but more recent interpretations of ACM style distributions among the Maya demonstrate that ACM may have also served as a marker of ethnic identity (Duncan, 2009; Tiesler, 2010) or social status (Wood, 1979).

The practice of ACM is well known from the continent of South America (Virchow, 1892). Modified crania are broadly found among groups residing in the modern day Colombia, Venezuela, Amazonian Rainforest, Ecuador, Peru, Bolivia, and north and central parts of Argentina and Chile between approximately 7000 B.C. and modern day (Dingwall, 1931; Lucena, 1965; Munizaga, 1976; Paredes Borja, 1966; Tommasco and Drusini, 1984). The most commonly cited motivation among these groups is that ACM served as a marker of ethnic identity between highland and lowland groups (Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; de la Vega, 1966 [1609]). There are, however, other motivations noted in the literature that may have driven this practice, including ACM as a marker of social status (de las Casas, 1892 [1561]; Torquemada, 1995 [1557-1664]), a delineator of sex differences (Weiss, 1961), a preventative measure against attack from evil spirits (Cobo, 1979 [1653]; Weiss, 1961), a means of improving health and work ethic (Cieza de Leon, 1984 [1553]; Morton, 1839), inhibiting intelligence and sense (Fernandez de Piedrahita, 1881), and the creation of a ferocious appearance in battle (Torquemada, 1995 [1557-1664]).

As demonstrated in this review, there are several different motivations cited for the practice of ACM among the same or similar groups by region. It is therefore difficult to determine which of the cited motivations is the actual one that drove the practice of ACM. Some motivations noted within this review were identified by the practicing groups (emic), while others were identified by an outsider (etic) (Harris, 1976). The confusion in the literature regarding the motivations could be related to emic vs. etic distinctions of the practice.

2.2 Artificial Cranial Modification-Related Growth Changes

The study of ACM-related growth changes has dominated the ACM literature for over a century. These types of studies fall into two broad categories: 1) the effects of ACM on craniofacial growth, and 2) the effects of ACM on epigenetic traits. The purpose of determining if, and the extent of, ACM-related change on these areas directly affect other areas of research, including but not limited to the relationship between genetics and environment on craniofacial growth and the association with biological distance studies. The following section will present a brief but comprehensive literature review on both of these areas of research.

2.2.1 Artificial Cranial Modification and Craniofacial Growth Studies

Some of the earliest studies of ACM focused on ACM-related craniofacial growth changes. Scholars easily pin-pointed cranial vault changes associated with each ACM style, but a vast debate concerning cranial base and facial changes began and continues today. One of the earliest studies was conducted by McGibbon (1912). McGibbon noted cranial base changes that he related to ACM. A separate study on Pacific Northwest Coast populations demonstrated fronto-occipital modification caused cranial base changes, particularly in the creation of basal platybasia, or a more obtuse cranial base angle (Oetteking, 1924). A study by Moss (1958) found different cranial base changes related to different ACM styles among North and South American groups. Moss's "vertical" group demonstrated basal kyphosis (acute angling of the cranial base), while the "oblique" group more often demonstrated platybasia. McNeill and Newton's (1965) study on Pacific Northwest Coast groups practicing fronto-occipital and annular modification found no difference in the cranial base angle between the two styles. Their results showed that both ACM styles demonstrated platybasia, which contradicts the results of Moss (1958). A study by Bjork and Bjork (1964) on ancient Peruvian crania demonstrated that modified crania had shortened cranial bases. They also examined the extent to which asymmetry affected craniofacial change and they found that the side with greater asymmetry had the greatest amount of change. Schendel *et al*. (1980) found no difference in cranial base angles between modified Hawaiian and unmodified crania. Anton (1989), who examined annularly and fronto-occipitally modified Peruvian crania, found platybasia present in both crania modified in either ACM style, agreeing with Oetteking (1924) and McNeill and Newton (1965).

More recent studies focusing on a single ACM style have not aided in clarifying these various results. Cheverud *et al*. (1992) studied fronto-occipitally modified from the Ancon site in Peru and the Songish groups from the Pacific Northwest Coast. They noted that while both groups practiced ACM with similar styles, they used different modification devices. The two samples demonstrated similar craniofacial changes: both demonstrated a widening anterior cranial base and shallower posterior cranial base. Kohn *et al*. (1993) studied annularly modified crania from two Pacific Northwest Coast groups, the Kwakiutl and Nootka. While the samples are geographically close, ACM styles for each group were produced by different devices and could account for the differences in cranial base changes found in each group. The Kwakiutl crania exhibited an increase in size in an anterior-posterior direction but a reduction in size in the medial-lateral and superior-inferior directions. There were, however, no significant changes in cranial base dimensions among the modified Nootka crania. Kohn *et al*.'s (1995) study on cradleboarded Southwestern United States crania (thus producing lamboidal flattening) found no significant cranial base changes when no asymmetry was present, but it did identify a few endocranial shape changes, most notably with blood vessels, which were produced when asymmetry was present.

The ACM-related changes in the face remain one of the most controversial topics in the study of the biological changes induced by ACM, particularly given the role facial metrics play in biological affinity studies (Table 2.1). The earliest study of ACM and its effect on facial metrics determined that ACM did create differences between modified and unmodified individuals (Hrdlicka, 1914). Oetteking (1930) identified specific facial changes such as greater nasal, upper facial, and orbital heights were present in annularly modified crania Pacific Northwest Coast populations.

These results were not demonstrated in a study of cradleboarded Lebanese crania by Ewing (1950). This study found no facial differences present in modified crania as compared to unmodified crania. Results derived from a study by Blackwood and Danby (1955) on Polynesian groups who practiced annular modification also found no differences in facial measurements between modified and unmodified crania.

Bjork and Bjork (1964) identified facial and mandibular changes in their fronto-occipitally modified Peruvian crania, and like the changes noted in the cranial base, these changes were more pronounced on the side with the greatest asymmetry. A similar study on North and South American crania found no change in facial metrics between crania with fronto-occipital modification and no modification, but crania with annular modification demonstrated changes in the palate and orbits when compared to unmodified crania (Rogers, 1975). These orbital changes were also found in a study of Pacific Northwest Coast groups by Cybulski (1973).

In light of these debates, Cocilovo (1975) sought to determine which facial measurements were unaffected by the changes caused by ACM in order to allow for the continued use of facial metrics in biological affinity studies. This study on Argentinean populations demonstrated ten facial measurements that were unaffected by modification and therefore could be used in biological affinity studies. These results were later supported by Rothhammer *et al*. (1982) in their study of ancient Andean groups but have recently been challenged by Rhode and Arriaza (2006) who found that several of these measurements are indeed different between modified and unmodified northern Chilean crania.

The study of the effects of ACM on facial metrics did not cease after Cocilovo's (1975) study. Schendel *et al*. (1980) demonstrated that among fronto-occipitally modified crania there was a tendency toward greater upper facial heights, and Brown (1981) found no corresponding facial breadth changes but did find increased facial and orbit heights in

Australian modified crania. Brown's results agree with the results produced by Schendel *et al*. (1980) but in part contradict those reached by Cocilovo (1975).

Anton (1989) attributed facial changes observed in her Peruvian samples to the cranial vault, not cranial base, changes as others had speculated. She noted different facial metric changes between fronto-occipitally and annularly modified crania, with the former having a tendency toward changing the orbits and creating a longer and narrower face and the latter producing a wider and higher face. Cheverud *et al*. (1992) found facial differences in both Ancon and Songish fronto-occipitaly modified crania but noted the facial changes in the Songish crania were more pronounced, purportedly because these crania had a more pronounced fronto-occipital modification style. Kohn *et al*. (1993) found small but statistically significant changes in facial metrics in annularly modified Kwakiutl and Nootka crania, but they found even fewer significant facial differences in facial metrics when studying cradleboarded Southwestern Indian crania (Kohn *et al*., 1995).

More recent studies continue to reach differing conclusions. Friess and Baylac (2003) found no facial differences were present between modified Peruvian fronto-occipital crania but found differences in facial metrics were present between annular crania and unmodified crania. Manriquez *et al*. (2006) did note facial metric differences between modified and unmodified northern Chilean crania. Ross and Ubelaker (2009) found no facial differences in fronto-occipitally modified Peruvian crania versus unmodified Peruvian crania. Pomeroy *et al*. (2010) found significant differences in facial metrics in their "bilobed" Peruvian samples when compared to unmodified crania, but none in the remaining ACM styles they identified. They also noted some changes were population specific and that these may or may not be directly related to ACM or ACM styles.

Table 2.1: Summary of Artificial Cranial Modification and Facial Changes Literature

Reference	Typology	Population	Results
Hrdlicka (1914)	Modified & Unmodified	Peruvian	ACM affects facial metrics.
Oetteking (1930)	Annular	Pacific Northwest Coast	ACM affect facial metrics.
Ewing (1950)	"Cradleboarded"	Lebanese	ACM did not affect facial metrics.
Blackwood and Danby (1955)	Annular	Polynesian Groups	ACM did not affect facial metrics.
Bjork and Bjork (1964)	Fronto-occipital	Peruvian	ACM affect facial metrics.
Cybulski (1973)	Annular & Antero-Posterior	Pacific Northwest Coast	ACM affects facial metrics.
Rogers (1975)	Annular & Fronto-occipital	North & South American Groups	Annular modification affects facial metrics. Fronto-occipital modification does not.
Cocilovo (1975)	Modified & Unmodified	Argentinian	Identified 10 facial measurements not affected by ACM.
Schendel et al. (1980)	Fronto-occipital	Hawaiian	ACM affects facial metrics.
Brown (1981)	Modified & Unmodified	Australian	ACM affects facial metrics.
Anton (1989)	Annular & Fronto-occipital	Peruvian	ACM affects facial metrics.
Cheverud et al. (1992)	Fronto-occipital	Peruvian and Pacific Northwest Coast	ACM affects facial metrics but differently among the two geographically separate groups.
Kohn et al. (1993)	Annular	Pacific Northwest Coast	ACM affects facial metrics but differently among the two geographically separate groups.
Kohn et al. (1995)	Occipital Flattening	Southwestern USA	ACM affects facial metrics but minimally.
Friess and Baylac (2003)	Annular & Fronto-occipital	Peruvian	Annular modification affects facial metrics. Fronto-occipital modification does not.
Rhode and Arriaza (2006)	Annular & Tabular	Northern Chilean	ACM affects facial metrics.
Manriquez et al. (2006)	Annular & Fronto-occipital with Oblique and Erect Variants for both	Northern Chilean	ACM affects facial metrics.
Ross and Ubelaker (2009)	Fronto-occipital	Peruvian	ACM did not affect facial metrics.
Pomeroy et al. (2010)	Various	Peruvian	"Bilobed" styles demonstrated facial metric differences, but remaining styles did not.

2.2.2 Artificial Cranial Modification and Epigenetic Traits Studies

The second most prominent ACM-related growth change study from over the past century concerns the relationship between ACM and epigenetic trait incidence. Dorsey (1897) first described these effects when he noted that annularly modified Kwakiutl crania demonstrated different incidences of epigenetic traits as compared to unmodified crania. This conclusion was supported by other studies (Cilento, 1921; McGibbon, 1912; Oetteking, 1930), but Dingwall (1931) found no differences present. Given the rise of new methods and the complications associated with using epigenetic traits in biological affinity studies, the study and use of these traits fell out of favor until around the 1950s-1960s. Shortly after this resurgence, studies concerning the effects of ACM on these traits were published. El Najjar and Dawson (1970) and Gottlieb (1978) found while epigenetic trait frequency was affected by fronto-occipital modification styles in Southwestern United States groups, the incidence of these traits was not. Ossenberg (1970), however, found that both frequency and incidence was affected among fronto-occipitally modified crania in similar populations that she studied.

More recent studies have not aided in clarifying the debates concerning the effects of ACM on epigenetic traits. Anton *et al*. (1992) found no differences in incidence or frequency for sutural bones between modified and unmodified Peruvian crania, but Gerszten (1993), Guillen (1992), and White (1996) reached different conclusions when they identified differences in incidence and frequency of epigenetic traits between the modified and unmodified northern Chilean and Maya crania they sampled. Konigsberg *et al*. (1993) completed one of the most comprehensive studies on the ACM-related effects on epigenetic traits in several different North and South American populations and determined that while ACM will affect epigenetic trait incidence that the overall effect is minimal and therefore was not a concern in biological affinity studies. Studies by O'Loughlin (2004) on prehistoric and historic North American groups and Wilczak and Ousley (2009) on New Mexican groups agreed with the Konigsberg *et al*. (1993) study in that they noted some ACM-related effects on epigenetic traits but also noted that the traits demonstrating the most change were located near the areas of modification device placement. Several other studies on populations world-wide noted that ACM affected epigenetic trait incidence (del Papa and Perez, 2007; Sanchez-Lara *et al*., 2007; van Arsdale and Clark, 2011), but van Arsdale and Clark (2011) noted Filipino crania exhibiting lambdoidal flattening did not demonstrate any change in epigenetic traits as compared to unmodified crania. This result is in conflict with several studies that specifically indicated change in the occipital bone (cf. O'Loughlin, 2004; White, 1996).

Table 2.2: Summary of Artificial Cranial Modification and Epigenetic Trait Literature

Reference	Typology	Population	Results
Dorsey (1897)	Annular	Kwakiutl	ACM affects epigenetic trait frequencies.
McGibbon (1912)	Modified & Unmodified	Various	ACM affects epigenetic trait frequencies.
Cilento (1921)	Modified & Unmodified	Australian	ACM affects epigenetic trait frequencies.
Oetteking (1930)	Annular	Pacific Northwest Coast	ACM affects epigenetic trait frequencies.
Dingwall (1931)	Various	Various	ACM does not affect epigenetic trait frequencies.
El Najjar and Dawson (1970)	Vertical occipital and lambdoidal flattening	SW Pueblo Indian & Modern	Epigenetic trait frequency is affected but incidence is not.
Ossenberg, (1970)	Bifrontal modification or none	Hopewell	Epigenetic traits affected incidence and frequencies.
Gottlieb (1978)	Lambdoidal Flattening	SW Indian	No affect on epigenetic trait incidence but does affect frequencies.
Anton et al. (1992)	Fronto-occipital, annular, undeformed	Peruvian	No affect in incidence or frequency.
Guillen (1992)	Annular & Fronto-occipital Flattening	Northern Chilean	ACM affects epigenetic traits incidence and frequency.
Konigsberg et al. (1993)	Fronto-occipital, annular, lambdoidal flattening	Hopi, Nootka, Kwakiutl, Peruvian/ Ancon	Minimal affect on epigenetic traits.
Gerszten (1993)	Allison *et al.*, 1981	Northern Chile	Does affect epigenetic trait incidence.
White (1996)	Tabular oblique or undeformed	Maya	Affects epigenetic trait frequencies.
O'Loughlin (2004)	Various	North American Groups	Minimal affect on epigenetic traits.
del Papa and Perez (2007)	Modified & Unmodified	Argentinian	Does affect epigenetic trait incidence.
Sanchez-Lara et al. (2007)	Fronto-occipital	Mexican, Peruvian, Modern	Does affect epigenetic trait incidence.
Wilczak and Ousley (2009)	Occipitally Modified & Lamboidally Modified	New Mexican	Minimal affect on epigenetic traits.
van Arsdale and Clark (2011)	Fronto-occipital & Lambdoidal Flattening	Filipino	Fronto-occipital modification does affect epigenetic trait incidence, lambdoidally flattened crania does not.

As specified above (and summarized in Table 2.1 and 2.2), there remains little consensus in the literature concerning the growth changes related to ACM. Several rationales have been offered to explain these inconsistencies, including the improper comparison of genetically similar or different populations, different ways of acquiring data, different means of analyzing the data, different typologies, and other factors (e.g. interobserver error and small sample sizes) (Cocilovo *et al.*, 2011). Further scrutiny of these studies demonstrates that each study was fundamentally different in some way (e.g. differences in sampled populations, means of data acquisition, methods, and typologies). The combination of differences makes it difficult to pinpoint one factor which caused the inconsistency in results, but typological designations (i.e. lumping vs. splitting ACM styles) of the crania may be a key factor responsible for the differences in results (see section 2.3).

2.3 Typological Designations of Artificial Cranial Modification Styles

From the beginning of the study of ACM, scholars understood the necessity for specific classificatory systems in which to categorize the various modification types observed in each population under study. There were trends among scholars in their creation of ACM typologies, ranging from the simple to expanded, as scholastic needs and preferences changed over time. Scholars who created simple typologies cited several motivations, including devices used, generalizations of cranial form, and the need for simplicity, as the reasons creating simple typologies, whereas scholars who created expanded typologies claimed that the simple typologies reduced the actual diversity in ACM styles that were possibly purposefully created and held a specific meaning. This disagreement among scholars has generated several different ACM typologies, many of which were derived from South American populations despite ACM being a world-wide phenomenon.

The first ACM typologies created followed a simplistic typology scheme, with scholars identifying 3 to 4 modification styles (Flowers, 1881; Morton, 1839; Virchow, 1892; von Tschudi, 1846). Many of these typologies were derived from South American populations, primarily Peru and Chile (Morton, 1839; Virchow, 1892; von Tschudi, 1846), but some typologies were derived from additional cultural groups world-wide (Flowers, 1881; Morton, 1839). Gosse (1855) was the only scholar during this time to create an expanded typology, identifying 16 different modification styles from various groups world-wide. He believed the other typologies were too quick to ignore the diversity of ACM styles within a population, which he thought represented purposeful variations that held meaningful importance to the group or society.

The turn of the century brought about the creation of additional ACM typologies, starting with Hrdlička (1912). Hrdlička (1912) based his typology on South American populations, particularly coastal and highland groups, and devices, boards and textiles. He identified 2 primary ACM forms. He was a firm believer in simple typologies, claiming that expanded typologies placed too much emphasis on 'unintentional' variations that were often identified as stylistic diversity. This typology was followed by an additional typology, focusing on Peruvian groups and involved several criteria, including cranial form, devices, and cultural affiliation, in the overall formation of the typology (Tello, 1928), and there were at least 5 ACM styles ultimately identified. This typology, while utilizing some of the same criteria as employed by Hrdlička (1912), reached a very different conclusion, and it caused scholars to question simple typologies and the means by which they were created. Dingwall (1931) published a lengthy argument regarding this overall debate about simple versus expanded typologies, and he ultimately concluded that specific criteria, particularly ACM device, should be considered more strongly than others in the creation of ACM typologies.

Dembo and Imbelloni (1938) were among the first to attempt to create an ACM typology partially divorced from the previous criteria. Their typology, which identified 5 ACM styles, was created with cranial form and modification devices taken into consideration but ultimately supported by metric analyses as a means to fully identify and validate their identified styles. The use of metric analyses for ACM style identification was quickly abandoned by subsequent scholars. Neumann (1942) resorted to contextual information such as archaeological time period and cultural affiliation, geographical location, and final cranial form in the creation of his 7 ACM style typology derived from eastern United States aboriginal groups. Weiss (1961) identified 12 different modification styles, which he associated with particular archaeologically defined cultural groups of South America. Munizaga (1976) created a typology of 4 ACM styles found among Ecuadorian groups. Allison *et al*. (1981) identified 11 modification devices but 14 different modification styles, highlighting the possibility that specific modification styles may be created from one or more modification devices.

Imbelloni (1925) suggested that the reason for the proliferation of ACM typologies was due mostly to the inability of scholars to agree upon the classification of the observed ACM types. A review of the various ACM typologies, particularly those derived from the same population, exemplifies this point since scholars often do not recognize the same ACM styles. As Weiss (1961) points out, the number of existing ACM typologies available to scholars is, in part, due to the fundamental flaw of typological formation that requires the creator to identify ACM styles by their prescribed criteria, which varies by scholar and typology, and no one typology can or will identify all the real variation in ACM forms present in any given population. While scholars have suggested solutions to this problem for typology creation (Dingwall, 1931; Weiss, 1961), they appear to have been largely insufficient.

Many of the existing ACM typologies, particularly the expanded typologies, are no longer commonly used. The reason is, in part, because it is extremely difficult for scholars to classify ACM styles consistently when there are too many options to choose from (Cocilovo *et al.*, 2011; Weiss, 1961), and other scholars claim that the proliferation of ACM styles is in reality unintentional variations of primary styles (Dingwall, 1931; Weiss, 1961). This has left scholars to abandon the use of some typological designations in favor of others due to their apparent "better" accuracy in identifying ACM styles practiced within a group. As well, scholars note that the division of the simpler ACM typologies into a larger scheme that accounts for stylistic variation(s) runs the risk of atomizing the sample and making it too difficult to accurately statistically test (Cocilovo *et al.*, 2011). The collapse of different ACM types, however, runs the risk of ignoring important stylistic variations which can hold multiple meanings.

Several studies focusing on the biological effects of ACM on the skull and the cultural motivations of ACM have used various simplified ACM typologies (e.g. Anton *et al.*, 1992; Blom, 1999, 2005a & b; Blom *et al.*, 1998; El Najjar and Dawson, 1970; Gottlieb, 1978; Konigsberg *et al.*, 1993; Ossenberg, 1970; Sanchez-Lara *et al.*, 2007; Torres-Rouff, 2002, 2003, 2009; van Arsdale and Clark, 2011; White, 1996; Wilczak and

Ousley, 2009). There appear to be several advantages to using simple typologies, including minimizing the division of the sample (particularly when the sample size is small) and the appearance of a reduction in ACM style misidentification, which seems to reduce error and apparently produce "better" studies. This trend, however, may be a great detriment to the study of ACM as it does not account for real variability in ACM styles that may exist in a sample. For example, scholars working in southern Peru and northern Chile identified 14 different ACM styles (believed to have been created from one or more of the 11 modification devices they also identified) (Allison *et al.*, 1981). While this typology has only been used for the populations from which it was derived, the variability of ACM styles among these populations appears to be broadly accepted as being real (Cassman, 1997 & 2000; Cocilovo *et al.*, 2011; Manriquez *et al.*, 2006; Sutter, 2005). This conclusion demonstrates that the variability in ACM styles may be a factor that should not be ignored, contra Dingwall (1931) and Hrdlička (1912).

But what should be done? Should scholars use simplified or expanded typologies? This argument has been indirectly addressed over the years when discussing the use of analogy in archaeology. Analogy within archaeological contexts is the means of comparing known behavior with unknown behavior based on shared characteristics (e.g. material culture or environment) (Ascher, 1961). Specific models for testing human behavior are derived from analogies and studies employing analogies (Wylie, 1985). ACM typologies are the models in which some human behaviors are tested, e.g. cultural motivations of ACM, population movement, group identification, etc.

There are, however, several problems associated with the use of analogy based models which apply to the use of ACM typologies, including 1) the misuse of the models in data analysis (Wylie, 1985), 2) the models over-simplify human behavior (Shelley, 1999), and 3) models often complicate interpretations of human behavior and biological effects (Morwood, 1975). The use of inappropriate models to test human behavior among ACM studies is commonplace and takes the form of using typologies derived from one population but applying them to a different population, which may result in flawed or inaccurate interpretations. This error is commonplace in studies examining ACM and human behavior, particularly concerning the origination of various typologies as signifying particular social (or ethnic) groups. The second problem, that models can over-simplify human behavior, is also common among all types of ACM studies. When a model is too restrictive, it can unintentionally predict or guide the result and subsequent interpretations. A third concern that must be addressed is how models often complicate interpretations of human behavior and biological effects (Morwood, 1975). When too many options are available to explain the effects or motivations of ACM, one may find it difficult to narrow the focus and produce a result. These implications can lead to inaccurate interpretations in ACM studies (e.g. the social motivations of practicing ACM). Scholars must carefully choose the typology that best fits their research question, but no one typology seems best suited for all research purposes. One possible solution to this problem of ACM typologies is the use of multiple sources of analogy (Shelley, 1999).

2.4 Nested Typology: New Method, Possible Solution

A century's worth of study on the cultural and biological effects of ACM has not brought about a resolution to these debates. Different solutions have been suggested (e.g. similar methodologies and populations, larger sample sizes) and implemented (Cheverud *et al.*, 1992; Kohn *et al.*, 1993 & 1995; O'Loughlin, 2004), but there remains no consensus in results. A nested typology, which makes use of multiple sources of analogy, is being proposed here as one possible solution. A nested typology combines several different ACM typologies, particularly those which have been previously used in and derived from northern Chilean populations (Figure 2.1). Its creation is based on the simplest typology as the foundation typology with the remaining typologies branching out in increasing complexity. The kind of typologies and numbers of ACM styles identified within each tier of the nested typology dictates what the expectations are and can be of the data. Therefore, the expectations based on each typology will also range in complexity.

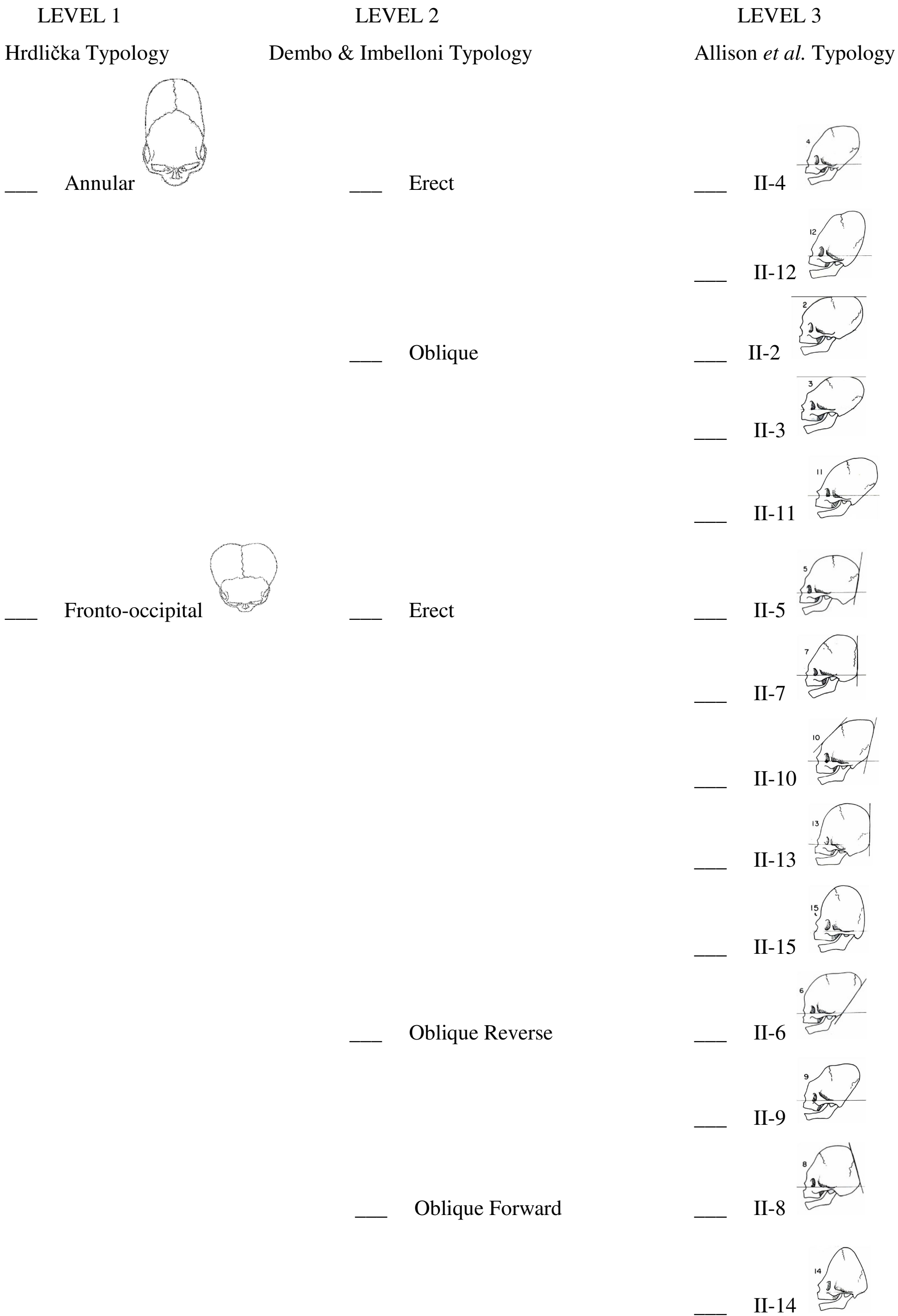
The nested typology presented herein (see Figure 2.1) was created based on typologies used in previous studies of ACM in northern Chile, (e.g. Allison *et al.*, 1981; Cassman, 1997 & 2000; Gerszten, 1993; Manriquez *et al.*, 2006; Sutter, 2005), the area under investigation for the scope of this doctoral research. Typologies created by Hrdlička (1912), Dembo and Imbelloni (1938), and Allison *et al.* (1981) were included in the nested typology. The foundation typology was the Hrdlička (1912) typology, and herein referred to as Level 1. This typology is the least complex as it only identifies two modification types: annular and fronto-occipital modification styles. The expectations derived from this typology are limited as no more than three groups can be identified (one unmodified and two modified). Further ACM style variation within each type cannot be recognized.

The Level 1 typology is followed by the Dembo and Imbelloni (1938) typology, herein referred to as Level 2. There are 5 modification styles identified, which include variants of the previously identified annular and fronto-occipital styles from Level 1. There are several more expectations that can be identified based on the Level 2 types. No more than 6 groups can be distinguished (1 unmodified and 5 different modified groups), which could distinguish more variation than in the previously identified ACM typology. This increased number of ACM styles increases the number of hypotheses, particularly concerning the number of social identities which can be recognized, that can be tested.

The next typology is the one created by Allison *et al.* (1981) that is referred to here as Level 3. Although these types were not directly derived from the previous two modification typologies, it was believed that they could still be related to them since the modification devices associated with the Level 3 styles are known. There are 14 modification styles identified, and no more than 15 groups or identities can be identified. Upon examination of the crania, however, it was apparent that the ACM styles 4, 11, 12, 14, and 15 identified by Allison *et al.* (1981) did not directly correlate with specific ACM styles previously identified in Levels 1 and 2, which could be related the number of ACM devices (11) not correlating with the number of ACM styles (14). The decreased number of modification devices may have required practitioners to use different modification devices to create the same intended modification style, hence the discrepancy in the ACM style identification. As well, Allison *et* al. (1981) only provided lateral line drawings of the ACM styles they identified, but they did not detail specific cranial criteria for each style. This lack of descriptive criteria forces scholars identifying styles based on this typology to make difficult decisions regarding the ACM style identification, particularly when the reality of the ACM styles do not exactly match those shown in the lateral line drawings.

Another explanation for the lack of correlation in the Allison *et al.* (1981) styles in the nested typology is that practitioners may have opted to mimic specific ACM styles with inappropriate modification devices in order to establish a more favorable identity for the affected individual, particularly if having a modified cranium ensured a better or easier life. Such mimicry was common in France where cranial modification was a custom reserved for and symbolized elite status but was secretly practiced by commoners who wanted to secure a better livelihood for their children (Brain, 1979). No matter the reason, this trend in the data makes it difficult to incorporate this typology into the nested typology, but the illustration in Figure 2.1 illustrates the concept of the nested typology.

Figure 2.1: Nested ACM Typologies (Images after Allison *et al.,* 1981; Anton, 1989)



There are several advantages to using a nested typology. The first is that the nested typology allows for multiple hypotheses to be tested by various means (i.e. typologies).

The simpler typologies, such as the Level 1 typology, do not allow for multiple hypotheses to be tested but instead are limited by the number of ACM styles present. If a scholar wishes to examine the cultural motivations of ACM among a particular group and the Level 1 typology is chosen, no more than 2 hypotheses can be tested as that is the most variability in ACM styles available for testing. It is inappropriate to employ the simpler typologies when hypotheses are being tested that posit the existence of several groups. As demonstrated in Figure 2.1, the Level 2 typology can collapse into the previous Level 1 typology, allowing for further scrutiny of an individual hypothesis or testing of multiple hypotheses in one sitting. Therefore, the nested typology allows for multiple means of hypothesis testing, ranging in complexity based on ACM typologies chosen, and may be a favorable means of data analysis for certain studies.

Another benefit of the nested typology is the comparability of results among different studies. The use of only one typology in a study means that the results of that study may only be comparable to studies utilizing similar or the same typology. If a nested typological approach is taken, the results of the study can be compared to multiple studies that utilized different typologies, maximizing the evaluation of numerous studies. This approach aids in determining the utility of the past studies but also demonstrates the utility of the typologies used in the research being conducted.

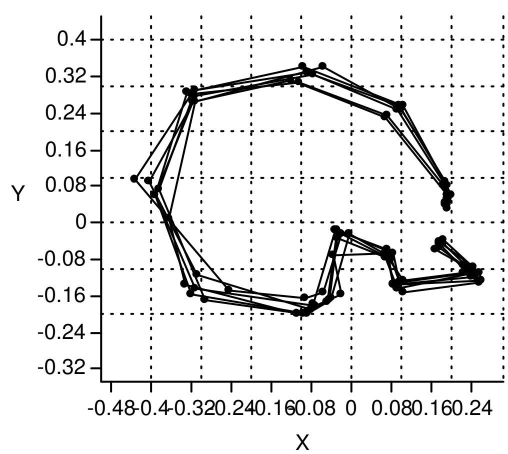
There is, however, at least one drawback with the nested typology. The first is that it can be time consuming if the typologies do not collapse perfectly (as occurred with the Allison *et al.* typology). Scholars utilizing the nested typology have to take time to identify various ACM styles, which depending on how the nested typology is set up can be a daunting task. In the case of the Level 1 and 2 typologies, it is a matter of simply expanding the original ACM style (fronto-occipital or annular) by identifying the additional traits (oblique or erect), which does not take up much time. This ease of identification is not the case when it comes to the Level 3 typology as the ACM styles identified in this typology do not easily collapse into the remaining typologies. Therefore, extra care must be taken in identifying ACM style for this level, and as previously mentioned by other scholars, the likelihood of misclassifying the ACM style increases (Cocilovo *et al.*, 2011; Weiss, 1961). The opposite is also possible in that ACM styles can be confirmed and more accurately identified by the nested typology if and where easy collapse occurs as additional time is necessary to identify multiple ACM styles, allowing for more time to catch mistakes.

2.5 Solution 2: Distinguishing Artificial Cranial Modification Styles Through Geometric Morphometric Analyses

As the nested typology has its own disadvantage and may not be considered optimal in all cases, a second solution is proposed herein that utilizes geometric morphometric analyses (GMA) to objectively identify ACM styles and, if possible, see if the GMA methods could reproduce any of the existing typologies, therefore highlighting the optimal typology that should be used for this sample. The use of metric and GMA analyses to confirm ACM styles has been recently used by Pomeroy *et al.* (2010), who utilized craniometric data, and Perez (2007), who utilized GMA analyzes, validating this method as a means of ACM style identification.

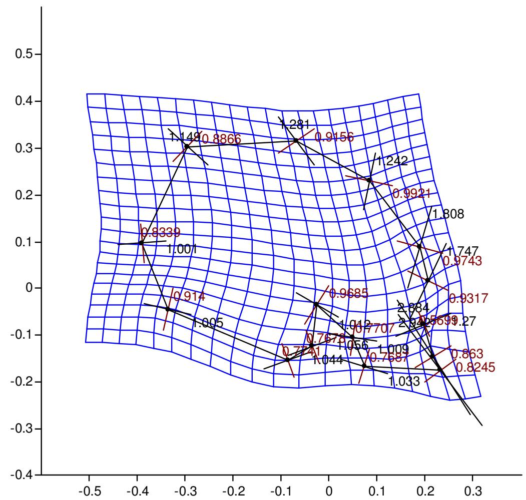
To complete this analysis to determine which ACM typology was best suited for these data, only complete adult crania with all cranial landmarks easily visible were used. Juvenile data were not utilized for several reasons, including differences in preservation, the lack of definitive styles present (as juveniles may exhibit intermediate ACM forms dependent on age), and small sample size. All modified and unmodified adult crania from the Formative, Regional Development, and Late Periods were surveyed as these periods were when ACM was commonly practiced. The tpsDIG program was used to digitize landmarks identified from scanned lateral X-ray images of the skull (Rohlf, 2001). Digitized data were input into the P.A.S.T. software package, and GMA procedures known as Procrustes Superimposition and Thin Place Spline analyses were used (Hammer *et al.*, 2005). Procrustes Superimposition rotates, translates, and reflects objects in order to compare the shape of objects (Cox and Cox, 2001) (Figure 2.2). Procrustes Superimposition turns the landmark data into Procrustes coordinates, bringing all objects to a standardized size, orientation, and position. This step is necessary before any further analyses can be done. This process removes size as a confounding factor, leaving shape as the only testable variable (Hammer and Harper, 2006). Thin Plate Spline analyses employ "shape" data in order to illustrate shape deformations amongst compared objects (Figure 2.3) (Hammer and Harper, 2006). Thin Plate Spline completes this task by placing a grid over the objects that bends where deformations occurs as related to a standard shape. The P.A.S.T. program provides choices in object comparison to either a mean shape or one standard object. In this study, one standard shape (an unmodified individual from the Chinchorro culture) was used. The data created by the GMA were input into a cluster analysis, and clusters were scrutinized via discriminant function analysis. The discriminant function analysis identified the 17 type cluster as the best cluster solution. An ANOVA test was completed on the craniometric measurements of the crania as an additional means of testing the reliability of the identified types, and the results demonstrated 17 different modification styles were present. These are not directly relatable to the previous typologies in the nested typology and nonmodified crania were not consistently placed in the same cluster. Therefore, the goal, determining the utility of the Level 1-3 typologies, was not achieved.

Figure 2.2: Procrustes Superimposition



This figure shows the Procrustes Superimposition after all the Procrustes coordinates have been translated and standardized in size and orientation, creating comparable objects.

Figure 2.3: Thin Plate Spline



This figure shows the warping of the grid overlaying the studied object in the Thin Plate Spline analysis. The numbers identify areas of strain and change as compared to the standard object.

While these results do not demonstrate which of these three typologies is best utilized in the analysis of these data, the large number of ACM styles identified does suggest that the variability in ACM styles is real, lending credence to expanded typologies (e.g. Allison *et al*., 1981). It also, however, underscores the potential issues regarding the objective recognition of the ACM types for these larger typologies and the reproducibility of their identification, which was a fundamental criticism of several scholars (Cocilovo *et al*., 2011; Dingwall, 1931; Hrdlička, 1912). There is also a possibility that the landmark data used to identify ACM styles within the scope of this method may not sufficiently capture the form changes induced by ACM, and therefore the identified styles are not accurately recognized based on the ACM styles that truly exist.

Ultimately, scholars examining ACM and ACM related subject matter must carefully chose the typology used in the scope of their research in order for it to best fit the question they are seeking to answer and the overall data set with which they are working. Simple and expanded typologies each have their place within the present research questions being examined. Scholars should take into account their research question, the origination of the typology chosen, sample size, and possible conclusions that may be reached when choosing the typology used within their study. Choosing the best typology for the research question will ultimately aid in producing better research.

2.6 Conclusion

In conclusion, there has been much study of topics concerning ACM, particularly concerning topics on the cultural motivations of ACM, the growth changes produced by ACM, and the classifications of ACM styles. The exploration of these topics has brought about more debate than resolution, and several explanations and criticisms of previous studies have been suggested to explain the lack of consensus in the literature (Cocilovo *et al.*, 2011). This current study of ACM seeks to explore some of these debates and do suggest some ways of addressing the criticisms. The use of genetically similar populations as well as basic and complex data acquisition techniques and analyses are at the forefront of addressing these issues. A nested typology incorporating previously used typologies and those derived from the sample population allows for ease in comparison of results among studies and in approaching the debates without losing variability in the data or sample size. This new methodology will hopefully lend itself to helping to resolving the current debates in the literature and further the knowledge on the topics concerning ACM and ACM studies.

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Chapter 3

3 Examining the Effects of Artificial Cranial Modification on Craniofacial Epigenetic Traits and Facial Metrics

Studies concentrating on features of the skull for the purpose of determining the biological similarities and differences among groups have dominated the field of physical anthropology for over a century (cf. Guillen, 1992; Hrdlička, 1939; Morton, 1839; Oetteking, 1930; Saunders and Rainey, 2008). The skull is divided into two primary regions: the neurocranium, made up of the cranial vault and cranial base, and viscerocranium, made up of the facial bones and mandible (Bishara, 2001; O'Higgins and Vidarsdottir, 1999; Scheuer and Black, 2000). Growth of the skull is believed to be interrelated among the various hard and soft tissues that compose it. Each cranial region grows at its own pace but is sensitive to, and dependent on, the pace of the growth of the remaining regions (Enlow, 1990; Enlow and Hans, 2008; O'Higgins and Vidarsdottir, 1999; Scheuer and Black, 2000). These complex relationships are summed up in the Functional Matrix Hypothesis (Moss, 1960, 1962, 1969), which maintains that the skull is made up of areas, known as matrices, dedicated to specific functions that are controlled and/or regulated by specific hard and soft tissue forms. Skeletal tissue growth responds to soft tissue growth related to the form and function of each matrix.

The craniofacial skeleton begins as mesenchymal tissue, an embryonic tissue (Enlow and Hans, 2008; Moyers and Enlow, 1988; Scheuer and Black, 2000), that eventually turns into one of two types of bone: endochondral or intermembraneous. Endochondral bone forms first into cartilage through a process known as chondrogenesis before eventually reaching a completely osseous state, whereas intramembraneous bone ossifies directly without any intermediary stages (Bishara, 2001; Enlow and Hans, 2008). Both of these bone formation processes occur during fetal development (Scheuer and Black, 2000). At birth, cranial growth is still widely incomplete and continues in the form of two growth processes: cortical displacement, also known as translation, and cortical drift, also known as remodeling, of bone (Bishara, 2001; Cohen, 2006; Enlow, 1990; Enlow and Hans, 2008). Cortical displacement is the process in which the bone physically changes location in space, whereas cortical drift is the process of reshaping the bone (Moyers and Enlow, 1988; O'Higgins, 2000). Both types of growth occur in all regions of the skull, although emphasis on each type varies by region and age of the individual.

The cranial vault bones, which house and protect the brain, are present as mesenchymal tissue by the fourth prenatal week but do not begin intramembranous ossification until the eighth (Bishara, 2001; Dixon, 1997; Moyers and Enlow, 1988; Proffett, 2007; Scheuer and Black, 2000). At birth, the cranial vault bones are partially ossified and are separated by the fontanelles, sutures, and cartilaginous tissue, making the skull highly plastic and susceptible to change in form. The ossification of the fontanelles and overall growth of the cranial vault occurs rapidly, with the cranial vault reaching 75-85% of its full size within the first two years of postnatal development before finally completing growth between the 7th and 8th year (Bishara, 2001; Cohen, 2006; Proffett, 2007; Ranly, 1988; Scheuer and Black, 2000). This skeletal growth is believed to be controlled and paced by the growth of the brain and related soft tissues (Brodie, 1941a & b; Enlow, 1990; Enlow and Hans, 2008; Moss, 1960, 1962, 1969; Moyers and Enlow, 1988; Scheuer and Black, 2000; Scott, 1954 & 1955).

The cranial base, which supports and protects the brain and spinal cord, is the only region to undergo endochondral bone development (Moyers and Enlow, 1988; Proffett, 2007). In prenatal development, the cranial base forms after the cranial vault and facial bones, presenting itself during the 4-5th week and starting endochondral bone formation during the 8-9th week (Bishara, 2001; Dixon, 1997; Scheuer and Black, 2000). Overall, the growth of the cranial base is controlled by cortical drift (Goodrich, 2005; Proffett, 2007). The cranial base continues to have a slower growth period after birth, which, in part, makes it very sensitive to growth changes (Enlow and Hans, 2008; Goodrich, 2005; Proffett, 2007; Scheuer and Black, 2000). The majority of cranial base growth is complete by age 7 or 8, on schedule with the cranial vault, but the spheno-occipital synchondrosis continues to grow until early adulthood, on pace with the growth schedules of the facial bones (Bishara 2001; Scheuer and Black, 2000).

The face and mandible support functions related to mastication, breathing, speech, facial expression, and housing of the organs (e.g. eyes and tongue) (Enlow, 1990; Enlow and Hans, 2008; Moyers and Enlow, 1988). This region undergoes intramembranous development, beginning in the 10th week of prenatal development (Moyers and Enlow, 1988; Proffett, 2007; Scheuer and Black, 2000). General ossification begins between the 3rd and 10th prenatal months (Scheuer and Black, 2000). After birth, growth in this region occurs in two stages: slow development between birth to 7 years, followed by rapid cortical drift from 7 years through early adulthood (Bishara, 2001; O'Higgins and Vidarsdottir, 1999; Proffett, 2007; Ranly, 1988; Shea, 1998). This growth follows a forward and downward pattern, allowing for the expansion of the bones, soft tissues, and organs (Cohen, 2006; Enlow and Hans, 2008; Moyers and Enlow, 1988; Proffett, 2007).

Craniofacial growth is believed to be primarily under genetic control, but several studies of both animal and human populations demonstrate that environmental factors (e.g. accidents, trauma, purposeful modification, disease, nutrition, socioeconomic status, etc.) can affect craniofacial growth (Brace and Hunt, 1990; Corrucini, 1974; Enlow and Hans, 2008; Mackey, 1977; Moyers and Enlow, 1988; Ranly, 1988; Shapiro, 1939). It is now known that certain environmental conditions can either delay or accelerate growth (Behrents, 1985; Moyers and Enlow, 1988). The role these environmental changes play in cranial growth patterns is particularly important as it is well documented that growth disruptions or changes in the cranial vault and cranial base will directly affect facial measurements (Enlow and Hans, 2008).

Facial metrics are widely used in physical anthropological studies concerning biological affinities. The use of facial metrics to determine biological affinities works on the premise that individuals of similar biological origin or affinity will share common facial morphology and therefore measurements, while those of different origin or affinity will be dissimilar enough to demonstrate statistically significant differences in comparison to other groups (Guillen, 1992; Hooton, 1946; Howells, 1973, 1989, 1995; Morton, 1839). Studies of the environmental factors affecting facial metrics are widespread, with scholars identifying environmental factors such as health, nutrition, geography, climate, and others as affecting growth (e.g. Buretic-Tomljanovic *et* al., 2007; Droessler, 1981; Corrucini, 1974; Hiernaux, 1966 & 1974; Mackey, 1977; Spradley, 2007; Smith *et al.*, 2007). One such environmental factor that is believed to affect growth is artificial cranial modification (ACM), but there exists a widespread debate concerning how ACM affects the facial skeleton and hence facial metrics. Despite a great deal of study on the matter, no clear consensus has yet been reached. Some scholars affirm that facial measurements are affected, regardless of modification styles and populations surveyed (Anton, 1989; Bjork and Bjork, 1964; Blackwood and Danby, 1955; Brown, 1981; Cheverud *et al.*, 1992; Cheverud and Midkiff, 1992; Cybulski, 1975; Frieß and Baylac, 2003; Kohn *et al.*, 1993; Kustar, 1999; Manriquez *et al.*, 2006; Oetteking, 1930; Ogura *et al.*, 2006; Pomeroy *et al.*, 2010; Rogers, 1975; Schendel *et al.*, 1980), and some believe no changes occur (Cocilovo, 1975; Rothhammer *et al*., 1982; Verano, 1987). These results are problematic as scholars continue to disagree on which measurements are affected, even when similar modification styles or populations are studied.

Solutions to the ACM problem have been suggested but these, too, remain the focus of extreme debate. Cocilovo (1975) published a study outlining 10 specific facial measurements that he argued are largely unaffected by cranial modifications of all kinds in a sample of Argentinean skulls. This set of measurements has been widely utilized by scholars working with ancient northern Chilean populations (Rothhammer *et al.*, 1982, 1983, 1984a, 1986; Rothhammer and Salvo, 2001; Rothhammer and Silva, 1990; Varela and Cocilovo, 2002), but Cocilovo's method was criticized by Rhode and Arriaza (2006) who found that ACM did affect facial measurements in both males and females in Chilean populations, calling into question the validity of these previous studies and the culture history interpretations based on them. Cocilovo *et al.* (2011) dismiss the results reached by Rhode and Arriaza (2006) and continue to defend their original conclusion (Cocilovo, 1975).

Because of the potential environmental effects on craniometrics, some scholars rely on an alternative means of studying biological differences in populations: epigenetic traits. Epigenetic, or the more general term nonmetric (Saunders and Rainey, 2008), traits are features such as Wormian bones or accessory ossicles (irregularly sized and shaped bony formations located within and along cranial sutures and fontanelles), foramina, bony spurs, canals, hyper and hypostotic traits, and grooves found on bones (O'Loughlin, 2004; White, 1996). These traits are popularly utilized for the purpose of understanding and distinguishing biological differences among groups due to their proposed heritable nature (Saunders and Rainey, 2008).

The use of epigenetic traits for these purposes has a long history within the discipline of physical anthropology. The study of cranial epigenetic traits was a popular area of study among scholars of the late 19th century who were focused on determining "racial" differences among groups, but the use of epigenetic traits to determine "racial" differences fell out of favor in the early 20th century when new methods were deemed more accurate and therefore favorable for this type of research (Saunders, 1977 & 1989). There was a revitalization in the use of epigenetic trait studies after several animal studies were completed (Berry, 1963; Berry and Searle, 1963; Deol and Truslove, 1957; Howe and Parsons, 1967; Grewal, 1962, cited in Molto, 1983; Grunenberg, 1952; Searle, 1954a). These studies demonstrated the potential genetic nature of epigenetic traits, which renewed the interest in their use.

These studies, however, were subject to several critiques, particularly concerning the conclusion that many believed overemphasized the genetic control of these traits (Deol and Truslove, 1957; Saunders, 1977; Searle, 1954a; Suchey, 1975). These studies noted that environmental factors, such as diet (Deol and Truslove, 1957; Searle, 1954a), sex (Searle, 1954a), maternal age (Howe and Parsons, 1967; Searle, 1954a & b), purposeful modification to the body, such as ACM (Adis-Castro and Neumann, 1948; Anton *et al.*, 1992; Bennett, 1965; del Papa and Perez, 2007; Dorsey, 1897; El Najjar and Dawson, 1977; Gerszten, 1993; Gottlieb, 1978; Guillen, 1992; Hrdlička, 1935; Montague, 1937; O'Loughlin, 2004; Ossenberg, 1970; Sanchez-Lara *et al.*, 2007; van Arsdale and Clark, 2010; White, 1996), as well as other factors (cf. Hauser and DeStefano, 1989; Suchey, 1975), did impact the incidence of epigenetic traits. More recent studies have expanded the list of environmental factors to include pathological conditions, although the extent and types of pathological conditions are imprecisely known (Saunders and Rainey, 2008).

These criticisms did not deter further nonmetric trait studies on human populations. Several studies (cf. Anderson, 1968a; Berry and Berry, 1967; Laughlin and Jorgensen, 1956) were published, with each utilizing different populations, statistical methods, and epigenetic traits. Despite the progress in the academic literature, these studies were also criticized for several reasons. Scholars noted these studies did not take into account several factors in their analyses, including sex and age differences (Akabori, 1933; Birkby, 1973; Buikstra, 1972; Corruccini, 1974; Cybulski, 1975; Finnegan, 1972; Gaherty, 1970; Jantz, 1970; Korey, 1970; Molto, 1983; Ossenberg, 1969, Winder, 1981); asymmetry/bilaterality of traits (Corruccini, 1974; Hertzog, 1968; Ossenberg, 1969; Truslove, 1961); the biological differences of groups, particularly when pooling of samples occurred (Suchey, 1975); temporal differences (Cadien *et al*., 1974); inter and intraobserver errors (Korey, 1970; Molto, 1983; Zeguara, 1973); and traits used (Korey, 1970; Ossenberg, 1976; Suchey, 1975). Several solutions were suggested, including equalizing the number of problematic traits surveyed (Finnegan, 1972 & 1978), removal of all problematic traits (Buikstra, 1972; Jantz, 1970), separating geographically distant groups (Buikstra, 1972; Korey, 1970; Saunders, 1989), and careful selection of traits (Molto, 1983; Ossenberg, 1969; Saunders, 1977 & 1989), but as very little consensus regarding the best course of action was reached, the use of epigenetic trait studies began to fall out of favor again.

Today, after several decades of refinement, epigenetic trait studies remain widely employed among studies seeking to determine biological group differences/similarities (cf. Alt *et al*., 1997; Blom *et al*., 1998; Blom, 2005; Christensen, 1998; Gao and Lee, 1993; Guillen, 1992; Hallgrimsson *et al*., 2004; Hanihara *et al*., 2003; Johnson and Lovell, 1995; Pardoe, 1991; Prowse and Lovell, 1995 & 1996; Spence, 1996; Sutter and Mertz, 2004). These methods have been deemed particularly favorable by scholars seeking to determine biological differences among ancient populations, making this one of the preferred methods among scholars working with ancient Andean populations (Blom, 2005; Blom *et al.*, 1998; Hoshower *et al.*, 1995; Jones, 1997; Sutter, 2005). ACM was widely practiced among Andean groups, and the effects of ACM on epigenetic trait incidences among these groups are imprecisely known or poorly described. The unknown effects of ACM are problematic, particularly among northern Chilean groups, as previous studies utilizing samples that included modified crania may be flawed. The purpose of this study is to determine if, and to what extent, ACM among northern Chilean groups affected epigenetic trait incidences and facial measurements, and how these effects relate to their use in biological distance analyses.

3.1 Materials and Methods

Materials for the epigenetic trait and facial measurement analyses were derived from ancient northern Chilean populations of the Azapa, Camarones, and Lluta Valleys that spanned a 9,000 year period from the Archaic to Late Periods (Table 3.1.). These individuals are currently housed at the Museo Arqueologico de San Miguel de Azapa in Arica, Chile. A total of 324 adult individuals were surveyed for these analyses, although the sample size varied for each analysis with the whole sample used for the epigenetic trait analysis but only 218 adults were used for the facial metric analysis. The reason for the discrepancy in sample sizes by analysis was due to the requirement of the mandible for the cephalometric analyses. Modified and unmodified crania were surveyed.

Table 3.1: Sample Make Up

Period	Cultural Phases	Dates	Coastal Sites	Inland Sites
Late Period	Gentilar Inca	A.D. 1476-1532	Camarones 8 and Camarones 9	Azapa 8 and Lluta 54
Regional Development	Chiribaya Maytas Maytas-Chiribaya San Miguel	A.D. 1100-1476	None	Azapa 6, Azapa 11, Azapa 71, Azapa 76, Azapa 140, Azapa 141
Middle Horizon	Tiwanaku Influence	A.D. 500-1100	None	None
Formative Period	Alto Ramirez Azapa El Morro El Laucho	1500 B.C.-A.D. 500	Playa Miller 7	Azapa 70 and Azapa 75
Archaic Period	Chinchorro Quiani	8000-1500 B.C.	Morro 1 and Morro 1-6,	Quiani 7

These samples included individuals from both coastal and inland contexts. Coastal and inland groups practiced their own unique cultures with coastal groups specializing in marine exploitation and inland groups specializing in agricultural practices. Several scholars believe that several periods, from the Formative to the Late Periods, were characterized by highland migration into the region (Berenguer and Dauelsberg, 1989; Goldstein, 2005; Moraga *et al.*, 2005; Muñoz, 1987; Piazza, 1981; Rivera, 1977 & 2008; Rothhammer *et al.*, 2002; Santoro, 1980a, b, c, 1981; Santoro and Ulloa, 1985; Varela and Cocilovo, 2002), and that coastal and inland groups represented isolated ethnic groups that remained in contact for trade purposes but possibly did not intermarry (Cassman, 1997 & 2000; Focacci, 1974 & 1993; Focacci and Chacon, 1989; Llagostera, 2010; Muñoz, 1981 & 1989; Rivera, 2008; Santoro, 1980a, b, & c).

An inventory and data collection, including sexing, aging, and cranial and facial metrics, was completed for all individuals. Only the cranium of each individual was examined due to the nature of the collections available at the time of data collection. Sex determinations were based on cranial morphology methods (Acsadi and Nemeskeri, 1970; Buikstra and Ubelaker, 1994). Age-at-death determinations were based on dental eruption. In adults, suture closure methods were deemed inaccurate for these individuals since modification can affect the timing of their closures (O'Brien and Sensor, 2008). Additional means of determining age among adults (e.g. dental wear patterns) could not be completed due to the scarcity of materials available (e.g. broken or missing teeth).

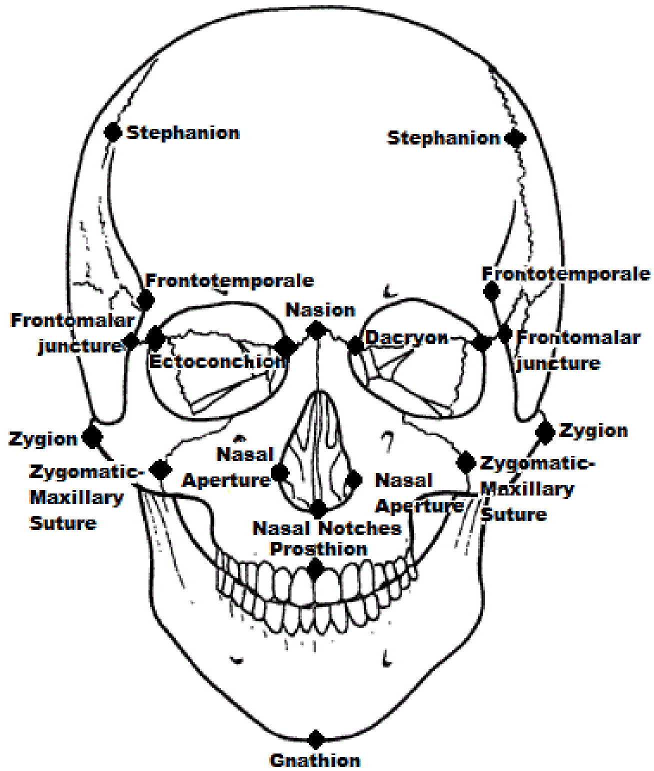
Crania were first scored for modification presence or absence. Modified crania were further scored for modification type based on the typology created by Hrdlička (1912). This typology identifies two modification styles: annular and fronto-occipital. Annular modification is a conical variation of the cranial form with reshaping occurring among several bones, including the frontal, temporal, inferior portions of the parietals, and occipital bones, and is believed to be caused by the application of wrapped materials (e.g. textiles, seaweed, kelp, etc.) (Hrdlička, 1912). Fronto-occipital modification is characterized by the flattening of both the frontal and occipital bones and is believed to be caused by the application of flat materials (e.g. boards, rocks, pads, etc.) (Hrdlička, 1912). Both styles were practiced with great frequency among ancient Andean groups (Blom, 2005; Dingwall, 1931; Hrdlička, 1912; Morton, 1839; Torres-Rouff, 2002 & 2009).

External osteometric measurements of the skull, herein referred to as craniometrics or cranial measurements (as appropriate), were taken to the nearest millimeter with either a spreading or sliding caliper based on procedures outlined in *Standards* (Buikstra and Ubelaker, 1994). Measurements were taken three times and, in cases of discrepancies, an average measurement was computed and used. Several cranial measurements were taken (see Table 3.2). Measurements were taken on the left side of the skull as applicable, and when and where the left side was unavailable (e.g. broken, missing, inaccessible, etc.), the right side was measured instead.

Table 3.2: List of Cranial measurements (following Buikstra and Ubelaker, 1994)

Upper facial height	Orbit height
Total facial height	Orbit breadth
Maximum frontal breadth	Interorbital breadth
Minimum frontal breadth	Biorbital breadth
Bifrontal breadth	Bijugal breadth
Bistephanic breadth	Palate breadth, external
Bizygomatic breadth	Palatal length, external
Bimaxillary breadth	Malar length, inferior
Nasal height	Malar length, maximum
Nasal Breadth	Cheek height

Figure 3.1: Location of External Cranial Landmarks



Epigenetic traits were scored as present or absent for all crania. A total of 28 cranial epigenetic traits (9 singular and 19 bilateral) were scored (Table 3.3). These included a variety of epigenetic traits such Wormian or accessory ossicles, foramina, canals, and hyper (e.g. condylar canal; foramen spinosum; clinoid bridging) and hypo-ostotic (e.g. metopic suture; os japonicum) traits. These traits were chosen due to their use in previous studies of Andean samples utilizing similar methods (Blom, 2005; Sutter and Mertz, 2004). The presence or absence of the 19 bilateral traits was scored for both the left and the right sides following the individual method (Green *et al.*, 1979; Molto, 1983). To increase the number of traits utilized in this analysis and in order to determine if ACM, particularly cranial asymmetry produced by ACM, affected one side more so than another, both the left and right sides were scored and analyzed separately. Traits were only scored when the cranial area was completely present. If damage to the skull was present or the pertinent cranial area missing, no scoring took place as it was impossible to determine the presence or absence of the trait.

Table 3.3: Epigenetic Traits Used in this Study (after Blom, 2005; Sutter and Mertz, 2004)

Metopic Suture (MS)	Bregmatic Bone (BB)
Supraorbital Foramen (SF) *	Lambdoid Bone (LB)
Parietal Foramen (PF) *	Asterionic Bone (AB) *
P. Condylar Canal Foramina (PCCF) *	Parietal Notch (PN) *
Divided Hypoglossal Canal (DH) *	Os Japonicum(OJ) *
Foramen Ovale (FO) *	Os Inca (OI)
Foramen Spinosum (FS) *	Maxillary Torus (MT)
Mastoid Foramen (MF) *	Palatine Torus (PT)
Zygomatic-Facial Foramen (ZFF) *	Condylar Facet (CF) *
Accessory Infraorbital Foramen (AIF) *	Clinoid Bridge/Spur (CB/S) *
Coronal Ossicles (CO) *	Mylohyoid Groove (MG) *
Sagital Ossicles (SO)	Mandibular Torus (MT2)
Lambdoidal Wormian Bone (LWB) *	Gonial Eversion (GE)
Occipit-Mastoid Wormian Bone (OMWB) *	Multiple Mental Foramen (MMF) *

* Bilateral Trait

The large breadth of literature concerning the effects of ACM on epigenetic traits has not reached a definitive conclusion regarding which, and the degree to which, each epigenetic trait will be affected. Based on the forces used in modification, it is expected that ACM will most likely affect epigenetic traits of the cranial vault, particularly the ossicles and wormian bones. The effects will likely vary by ACM style, as well. It is expected that annular modification styles will mostly likely increase the incidence of epigenetic traits that lay along the location of the modification device as this modification style inhibits lateral growth of the cranium and allows for compensatory, longitudinal growth. The fronto-occipital modification styles will most likely impact the expression of epigenetic traits that lay along the location of the modification device as this modification style inhibits longitudinal growth and allows for compensatory, lateral growth. Scholars are divided on the issue of if and how ACM affects cranial volume, with some demonstrating no effect (Cocilovo, 1975; Frieβ and Baylac, 2003; Marelli, 1914) and others demonstrating definitive changes (Cheverud *et al.*, 1992; Kohn *et al.*, 1993), and therefore changes in cranial volume among modified individuals will not be discussed in relation to epigenetic trait incidence. It is expected that there will be little to no ACM-related effect on the remaining traits. Table 3.4 outlines specifics of how each modification style will affect the epigenetic traits of the cranial vault.

Table 3.4: Expectations of ACM-related Changes to the Cranial Vault Epigenetic Traits

Epigenetic Trait	Annular Modification	Fronto-occipital Modification
Coronal Ossicles	Increase	Decrease
Sagittal Ossicles	Decrease	Increase
Lambdoidal Wormian Bones	Increase	Decrease
Occipit-Mastoid Wormian Bones	Increase	Decrease
Bregmatic Bone	Increase	Decrease
Lambdoid Bone	Decrease	Increase
Asterionic Bone	Increase	Decrease
Parietal Notch	Increase	Decrease
Os Inca	Decrease	Increase

The epigenetic trait data were then statistically tested by various means to determine if and to what extent ACM affected epigenetic trait incidence. The first statistical test conducted was the G-test (aka Likelihood Ratio). This test was conducted to determine if statistically significant differences in epigenetic trait incidence existed based on sex, trait correlation, site, and among modified and unmodified crania in general as well as for each period and geographical division of the data. This preliminary data testing with the G-test, herein referred to as data reduction, is required before any further analysis is conducted based on recommendations by several scholars (Irish, 2010; Molto, 1983; Saunders, 1977; Sutter and Mertz, 2004). The level of statistical significance for exclusion was originally set at 0.05, but this yielded too few traits for meaningful analysis. Consultation with Molto (pers. comm., 2012) determined that the significance level could be increased up to 0.20 in order to increase the number of traits that could be used. This increase doubled the number of traits that were used for each analysis when the data was divided by each period and geographical division, but there remained fewer than 15 traits that were used for each analysis. This result is similar to the number of traits utilized by a study conducted by Sutter and Mertz (2004) who also analyzed traits among several of these groups.

Additional tests were completed for each period and geographical division of the data via the Mean Measure of Divergence (or Distance) (MMD) test (Grewal, 1962, cited in Molto, 1983). The MMD test is a statistical test widely used to determine if biological distance (or difference) exists among groups surveyed. The MMD test completes this by first turning all the trait frequencies input into the program into angular values in order to stabilize the sample variance. These angular values are then weighted and compared in order to determine whether statistically significant distances exist among the groups (Molto, 1983). A non-significant result does not necessarily negate the existence of population difference (or distance) as it could simply mean that no difference could be gleaned from the available data (Sjovold, 1977). Sjovold (1977) states that insufficient types and number of variables could result in a non-significant result that is suggestive of no population difference. In the case of this analysis, all recommended data reduction techniques were completed as described above, reducing the likelihood of a non-significant result due to these factors. The MMD DOS Program version 1.0 created by Wright (unpub.) was used for this analysis. The data output produced by this program creates a data matrix divided diagonally down the center with the MMD in the upper right triangle and the standard deviations of MMD in the lower left triangle (Wright, unpub.).

Each skull was X-rayed in order to facilitate further analyses related to the facial metric changes related to ACM through cephalometric analyses. X-rays were taken on Kodak T-Mat G/RA Diagnostic Film with a Shimadzu EZY-RAD VA-125P-CH X-ray machine. X-rays were taken by Dr. Carlos Ubeda, Mayorie Chandia, Mariel Gonzalez, and the author at the museum, and Chandia and Gonzalez completed film development at the museum. Analyses of the X-rays were completed by the author at a private orthodontic facility in London, ON.

Cephalometry, or measurements of the living head, is a technique developed by anthropologists and refined by Holly Broadbent to quantify shape and sizes of skulls (Broadbent, 1931). Despite being popularly used in modern orthodontic practice today, there are several disadvantages associated with the use of cephalometric techniques, including the use of a 2 dimensional image to represent a 3 dimensional image (Ackerman *et al.*, 2012; Oszoy *et al.*, 2009); imperfect superimposition of cranial features either associated with natural facial asymmetry or flawed radiographic imaging

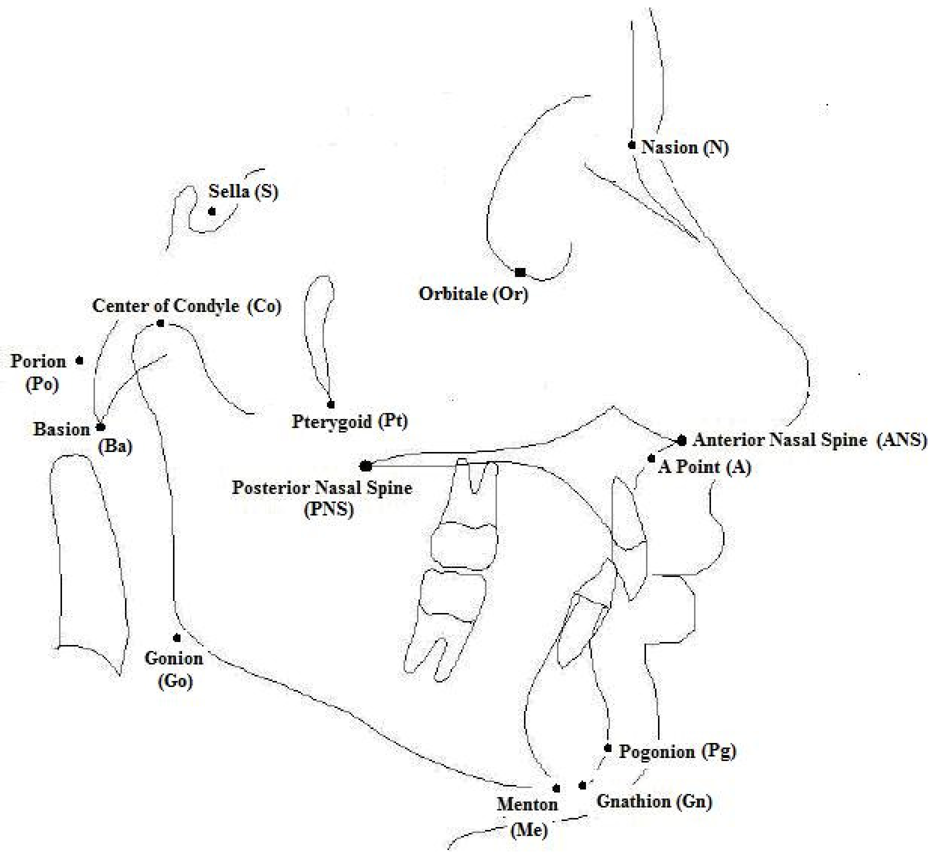
(Ackerman *et al.*, 2012; Harrel *et al*., 2002); errors with radiographic projection (Ackerman *et al.*, 2012); and misidentification of cranial landmarks and measurements (Ackerman *et al.*, 2012; Leonardi *et al*., 2008; van Vlijmen *et al*., 2009). These factors were controlled for as much as possible by the author and those assisting with X-raying. All crania were X-rayed at the same distance and same settings, meaning if radiographic projection occurred it was consistent among all radiographic images, and the crania were positioned similarly in order to control for superimposition of cranial features. Cranial landmarks were clearly visible in most crania as soft tissues were not present to obscure their presence on the image. Landmark identification was identified based on descriptions provided in the software program and was practiced in a pilot project prior to this analysis (Boston *et al.*, 2008). Several radiographs were retraced by hand and by the software program in order to test the accuracy of identification, and the landmarks were consistently identified. Measurements were taken by the software program, removing human error in misidentification.

Cephalometric analyses were conducted using the Kodak Orthotrac software (Kodak Orthotrac Practice Management Software Installation Guide, 2009). This program employs scans of X-rays to map internal and external facial landmarks, which are located by the user, and takes various measurements (herein referred to as cephalometrics or cephalometric measurements) based on the cephalometric analysis utilized. For the purposes of this study, a new analysis routine was created by Kodak Orthotrac utilizing a suite of measurements and angles chosen by the author in consultation with Dr. Drew Smith, a practicing orthodontist. This suite of cephalometric measurements was based on expected changes induced within the cranial base and face or solely the face in order to determine if ACM changed the facial convexity, height, and location of the mandible. It is expected, based on normal facial growth directions (as outlined in Section 3.1), that ACM would interrupt or halt normal growth by creating an increase in facial convexity and facial heights by interfering with the growth of the spheno-occipital synchondrosis in the forward and downward directional growth pattern outlined on page 55 (following Cohen, 2006; Enlow and Hans, 2008; Moyers and Enlow, 1988; Proffett, 2007). The cephalometric measurements chosen and expected outcomes are outlined in Table 3.5. It is easiest to increase facial measurements with modification as demonstrated in modern orthodontic practice (Smith *pers comm.*, 2012), and it is expected that all facial measurements surveyed in this study would demonstrate an increase in size among modified individuals as compared to unmodified individuals. The requested measurements were input into the new analysis (Figure 3.1). Only individuals with mandibles available (n=218) were surveyed as it was determined in a pilot study that cephalometric analyses could not be effectively exploited without the mandible present (Boston et al., 2008). The sample included 101 unmodified crania, 117 modified crania, and an equal number of male and female crania.

Table 3.5: Facial Measurements Used in Cephalometric Analyses (after Riolo *et al.*, 1974)

Measurement	Points	Type of Measurement	Expected Change
Sella-Nasion-A-point (A)	A-N-S	Angular	Increase
Sella-Nasion-Frankfort Plane (A)	N-S/Or-Po	Angular	Increase
Sella-Nasion-Palatal Plate (A)	N-S/ANS-PNS	Angular	Increase
Nasion-Sella-Gnathion (A)	N-S-Gn	Angular	Increase
Sella-Nasion-PM Vertical (A)	N-S/PTM-SE	Angular	Increase
Sella-Nasion-Basion (A)	N-S-Ba	Angular	Increase
Condylar Plane/Sella-Gnathion (A)	Or-Co/GN-S	Angular	Increase
Nasion-Pogonion/Mandibular Plane (A)	Go-Me/N-Pg	Angular	Increase
Anterior Nasal Spine-Nasion (L)	ANS-N	Linear	Increase
Sella-Nasion (L)	S-N	Linear	Increase
Basion-Nasion (L)	Ba-N	Linear	Increase
Menton-Nasion (L)	Me-N	Linear	Increase

Figure 3.1: New Cephalometric Analysis (after Kodak Orthotrac)



The cephalometric data for modified individuals were compared to the unmodified individuals. The cephalometric measurements of the unmodified sample were ultimately grouped together as there was a lack of statistically significant differences by site, region (coast vs. inland), period, or sex when the data were tested with an ANOVA or Student's T-test (Table 3.6). An average non-modified value for each measurement was determined after completion of the above statistical analyses, and these average values were used as the "standard" unmodified cephalometric values for comparison between the modified and unmodified individuals. The standard values were input into the new cephalometric analysis by Kodak to create a new analytical routine specified for the project. Modified individuals were then traced and compared to the measurements of the new cephalometric analysis. Upon completion of all tracings, the measurements (as determined by the Orthotrac software) were compared first with the Student's T-test to determine if statistically significant differences in measurements existed between modified and unmodified individuals, followed by the ANOVA test to determine if similar differences existed among annular and fronto-occipital modification styles and unmodified crania. Following these results, the (external) craniometric data were then analyzed with the Student's T-test and ANOVA in order to compare external measurement changes to those noted in the internal measurements determined by the cephalometric analysis.

Table 3.6: Unmodified Cephalometric Measurement Data

Cephalometric Measurements	**Site P-value (from ANOVA)**	**Region P-Value (from T-test)**	**Period P-value (from ANOVA)**	**Sex P-value (from T-test)**
Sella-Nasion-A-point (A)	.225	.199	.992	.863
Sella-Nasion-Frankfort Plane (A)	.723	.353	.461	.776
Sella-Nasion-Palatal Plate (A)	.190	.172	.965	.487
Nasion-Sella-Gnathion (A)	.221	.161	.117	.446
Sella-Nasion-PM Vertical (A)	.152	.638	.271	.392
Sella-Nasion-Basion (A)	.340	.384	.929	.554
Condylar Plane/Sella-Gnathion (A)	.132	.178	.181	.381
Nasion-Pogonion/Mandibular Plane (A)	.351	.164	.156	.262
Anterior Nasal Spine-Nasion (L)	.577	.127	.709	.935
Sella-Nasion (L)	.101	.183	.453	.340
Basion-Nasion (L)	.317	.232	.361	.178
Menton-Nasion (L)	.166	.264	.226	.871

As the purpose of this study was to determine if ACM affects epigenetic trait incidence and facial measurements and the extent of any changes that may exist, two null hypotheses were being tested. The first null hypothesis is that ACM had no effect on epigenetic trait incidence. This hypothesis would be rejected if analyses demonstrated statistically significant differences in epigenetic trait incidence are present between modified and unmodified individuals regardless of period and geographical region. As well, if this hypothesis was rejected, it would mean that biological affinity studies utilizing epigenetic traits will have to scrutinize the traits chosen in order to avoid the affects of ACM on the overall analysis. Failure to reject this hypothesis would mean that scholars utilizing epigenetic traits among these populations can do so freely and without scrutiny of modified crania. The second null hypothesis was that ACM had no effect on facial growth and therefore facial metrics. This hypothesis would be rejected if craniometric and cephalometric measurement differences are demonstrated between modified and unmodified individuals, which would mean that facial metrics could not be used to discern biological differences among groups for modified individuals within these populations. If, however, this hypothesis was not rejected, modified and unmodified crania within these populations could be used in biological affinity studies utilizing facial metric analyses.

3.2 Results

3.2.1 Epigenetic Traits

The first test that was completed was on unmodified cranial data in order to determine if coastal and inland valley groups represented separate coastal and highland groups. This test of the unmodified cranial epigenetic trait data demonstrated differences among all the unmodified crania by period (Table 3.7), requiring the data herein to be tested separately based on the geographical (coastal or inland valley) region and by period since the data could not be assumed to form a genetically and temporally uniform sample. The data were also pooled by valley for each period in order to increase sample sizes and increase statistical strength of each test.

Table 3.7: MMD Results for Unmodified Crania: All Periods

	Archaic	Formative	Regional Development	Late
Archaic	--	0.326*	0.123*	0.029
Formative	0.041	--	0.270*	0.211*
Regional Development	0.031	0.021	--	0.02
Late	0.04	0.029	0.019	--

**Significant Difference*

(Standard Deviations shaded)

As mentioned above, the epigenetic trait data were examined as a whole and then divided by period and geographical location (coastal valley vs. inland valley groups) in order to account for potential genetic differences related to possible highland migration into the region, and the results are presented as such herein.

All of the modified and unmodified cranial data were examined first to determine if ACM affected the incidence of epigenetic traits. The epigenetic traits were tested with the G-test. It was determined that 6 traits (21% of all traits surveyed) demonstrated statistically significant differences, but only two traits were ultimately used as the remainder demonstrated statistically significant differences by sex (Table 3.8).

Table 3.8: Traits Remaining After Data Reduction (All Data; Modified and Unmodified Crania)

Zygomatic Facial (Left* & Right)
Parietal Notch (Left* & Right*)
Os Japonicum (Right)*
Palatine Torus

**Sex differences present and therefore not used*

These two traits were input into the MMD analysis for the purpose of comparing modified and unmodified crania for epigenetic trait differences. The resulting MMD analysis demonstrated no distance (or difference) in epigenetic trait incidences between modified and unmodified crania for all the data (Table 3.9).

Table 3.9: MMD Results for All Data (Modified and Unmodified Crania)

	Mod	Unmod
Mod	--	0.017
Unmod	0.01	--

(Standard Deviation=0.01)

This result suggests that within the sample as whole (undivided by region or period) and with all modification forms combined, ACM does not affect epigenetic traits. As the previous analyses suggest biological distance (or difference) existed by region and period, the data had to be divided and analyzed separately.

3.2.1.1 Formative Period

The first period surveyed was the Formative Period, and the coastal and inland valley groups were surveyed separately. Epigenetic trait incidence between modified and unmodified individuals of the coastal valley group (FP) was analyzed with the G-test. Seven traits (25% of all traits surveyed) demonstrated statistically significant differences, but only 6 of the 7 traits were used in the MMD analysis as one was eliminated due to the incidences being statistically different by sex (Table 3.10). Analysis of the epigenetic trait incidence between modified and unmodified individuals of the inland valley group (FP) demonstrated 8 traits (29% of all traits surveyed) were statistically significant different, but one trait demonstrated sex differences and therefore could not be used (Table 3.10).

Table 3.10: Traits Remaining After Data Reduction (Formative Period; Modified and Unmodified Crania)

Coastal Valley Group *(FP)*	**Inland Valley Group *(FP)***
Supraorbital Foramen (Left & Right*)	Metopic Suture
Foramen Spinosum (Right)	Parietal Foramen (Right)
Mastoid Foramen (Left & Right)	Zygomatic Foramen (Left)
Asterionic Bone (Left)	Coronal Ossicle (Right)
Parietal Notch (Right)	Parietal Notch (Right)
	Os Japonicum (Left & Right)
	Multiple Mental Foramen (Left)*

**Sex differences present and therefore not used*

These incidences of these traits were then input an MMD analysis by region. The results of the coastal valley group (FP) MMD analysis demonstrated distance (or difference) between modified and unmodified individuals (Table 3.11), but no distance (or difference) was demonstrated between modified and unmodified individuals of inland valley group (FP) (Table 3.12).

Table 3.11: MMD Results for Coastal Valley Group (FP)

	Mod	Unmod
Mod	--	0.090*
Unmod	0.039	--

**Significant Difference*

(Standard Deviation=.039)

Table 3.12: MMD Results for Inland Valley Group (FP)

	Mod	Unmod
Mod	--	0.069
Unmod	0.056	--

**Significant Difference*

(Standard Deviation=.056)

Overall, these results suggest that ACM was affecting epigenetic trait incidence of these six traits among Formative Period coastal groups, but ACM was not affecting the epigenetic trait incidence of the seven traits among Formative Period inland groups. This discrepancy in results may be due to ACM style preferences between coastal and inland valley groups as both groups had a majority ACM style and that the styles affected the traits differently, or it could be due to the influx of outsider groups to the area (Guillen, 1992).

3.2.1.2 Regional Development Period

Only inland valley data were available in the Regional Development Period. Data reduction of the epigenetic trait data for this period demonstrated 15 traits (54% of all traits surveyed) with statistically significant differences between modified and unmodified individuals, but only 14 traits were used as one trait was eliminated due to sex differences (Table 3.13).

Table 3.13: Traits Remaining After Data Reduction (Regional Development Period; Modified and Unmodified Crania)

Inland Valley Group *(RDP)*
Metopic Suture
Supraorbital Foramen (Left)*
Paracondylar Canal (Left & Right)
Foramen Spinosum (Right)
Zygomatic Foramen (Left & Right)
Coronal Ossicle (Left & Right)
Lambdoid Bone
Asterionic Bone (Left)
Parietal Notch (Left & Right)
Condylar Facet (Left)
Mylohyoid Groove/Bridge (Left)

**Sex differences present and therefore not used*

These traits were then input into the MMD analysis. The results demonstrated distance (or difference) between modified and unmodified crania (Table 3.14).

Table 3.14: MMD Results for Inland Valley Group (RDP)

	Mod	Unmod
Mod	--	0.039*
Unmod	0.01	--

**Significant Difference*

(Standard Deviation=.01)

This result suggests that ACM was affecting epigenetic trait incidence of the fourteen traits among these Regional Development inland groups. This result differs from the Formative Period when ACM did not appear to be affecting epigenetic traits in the inland groups. The Regional Development Period is characterized by large scale migrations of groups due to the fall of the Tiwanaku polity (Rivera, 2008), and migrations into this region may have also occurred as a result of this event or other factor (Moraga *et al.*, 2005; Rothhammer *et al*., 2002; Varela and Cocilovo, 2002).

3.2.1.3 Late Period

The Late Period had both coastal valley and inland valley group data that could be analyzed. Among the coastal valley group, only five traits (18% of all traits surveyed) demonstrated statistically significant difference between modified and unmodified individuals when analyzed with the G-test, but only two traits were utilized for the MMD analysis as the remainder demonstrated significant differences by sex (Table 3.15). Six traits (21% of all traits surveyed) demonstrated statistically significant differences between modified and unmodified individuals of the inland valley group, but three traits were eliminated due to statistically significant differences by sex (Table 3.15).

Table 3.15: Traits Remaining After Data Reduction (Late Period; Modified and Unmodified Crania)

Coastal Valley Group *(LP)*	**Inland Valley Group *(LP)***
Supraorbital Foramen (Right)	Paracondylar Canal (Right)*
Divided Hypoglossal (Right)	Parietal Notch (Left)
Foramen Spinosum (Right)*	Os Inca*
Mastoid Foramen (Right)*	Maxillary Torus*
Mylohyoid Groove/Bridge (Left)*	Palatine Torus
	Multiple Mental Foramen (Left)

**Sex differences present and therefore not used*

The MMD analysis was conducted for both the coastal and inland valley groups of the Late Period, and the results from each analysis were different. The MMD analysis of coastal valley group demonstrated distance (or difference) between modified and unmodified individuals (Table 3.16), but there was no distance (or difference) noted between modified and unmodified of the inland valley group (Table 3.17).

Table 3.16: MMD Results for the Coastal Valley Group (LP)

	Mod	Unmod
Mod	--	0.629*
Unmod	0.238	--

**Significant Difference*

(Standard Deviation=.0238)

Table 3:17: MMD Results for Inland Valley Group (LP)

	Mod	Unmod
Mod	--	0.117
Unmod	0.116	--

**Significant Difference*

(Standard Deviation=.116)

These results suggest that ACM affects epigenetic trait incidence of the two traits among Late Period coastal groups, but ACM does not affect epigenetic trait incidence of the three traits among the Late Period inland groups. These results are consistent with the results from the Formative Period, but they are not consistent with the results of the Regional Development Period.

3.2.1.4 Hrdlička Typology

All of the epigenetic trait data were then examined as divided by the Hrdlička typology for the purpose of determining if particular ACM styles affected epigenetic trait incidences as compared to unmodified crania. The epigenetic traits were first tested with the G-test, and this analysis demonstrated 11 traits with statistically significant differences among the three cranial forms (annular, fronto-occipital, and unmodified crania), but only six traits were tested as these demonstrated no bias by sex (Table 3.18).

Table 3.18: Traits Remaining After Data Reduction (All Data; Hrdlička Typology)

Zygomatic-Facial Foramen (Left* & Right)
Occipito-Mastoid (Right*)

Supraorbital Foramen (Left* & Right)
Accessory Infraorbital (Left & Right*)
Asterionic Bone (Left)
Coronal Ossicle (Left)
Parietal Notch (Right*)
Condylar Facet (Right)

**Sex differences present and therefore not used*

The remaining traits were put into the MMD analysis for the purpose of comparing the cranial forms for epigenetic trait differences. The resulting MMD analysis demonstrated distance (or difference) in epigenetic trait incidences between annularly and fronto-occipitally modified crania and annularly modified and unmodified crania, but fronto-occipitally modified and unmodified crania demonstrated no distance (or difference) when compared (Table 3.19).

Table 3.19: MMD Results for All Data (Hrdlička Typology)

	Ann	FO	Unmod
Ann	--	0.145*	0.084*
FO	0.014	--	0.006
Unmod	0.011	0.011	--

**Significant Difference*

(Standard Deviations shaded)

These results demonstrated that annularly modified crania affected epigenetic traits as relative to unmodified crania, but fronto-occipitally modified crania did not affect epigenetic traits relative to unmodified crania. As well, annular and fronto-occipital styles affected these traits differently as the MMD analysis demonstrated difference between the two styles.

3.2.1.5 Formative Period

The data were then divided by period and geographical region as above. The Formative Period was divided into a coastal and inland valley group. A total of 11 epigenetic traits demonstrated statistically significant differences among the various cranial forms, but two were eliminated due to possible sex bias, leaving 9 traits that could be used in the MMD analysis of the coastal valley group (FP-H) (Table 3.20). Among the inland valley group (FP-H) data, a total of 8 epigenetic traits demonstrated statistically significant differences and none were eliminated as these traits were not different by sex (Table 3.20).

Table 3.20: Traits Remaining After Data Reduction (Formative Period; Hrdlička Typology)

Coastal Valley Group *(FP-H)*	**Inland Valley Group *(FP-H)***
Metopism*	P. Condylar Canal Foramina (Right)
Supraorbital Foramen (Left & Right*)	Zygomatic Facial Foramen (Left & Right)
Foramen Spinosum (Left & Right)	Accessory Infraorbital Foramen (Left)
Mastoid Foramen (Left)	Coronal Ossicle (Right)
Coronal Ossicle (Right)	Condylar Facet (Left & Right)
Occipito-Mastoid Wormian Bone (Right)	Clinoid Bridge/Spur (Right)
Lambdoid Bone	
Asterionic Bone (Right)	
Parietal Notch (Right)	

These traits were input into the MMD program. The results for the coastal valley group (FP-H) demonstrated no distances (or difference) among all three cranial forms (Table 3.21). The results of the inland valley group (FP-H) data, however, demonstrated distance (or difference) between annularly and fronto-occipitally modified crania as well as fronto-occipitally modified and unmodified crania, but there was no distance (or difference) between annularly modified and unmodified crania (Table 3.22).

Table 3.21: MMD Results for the Coastal Valley Group (FP-H)

	Ann	FO	Unmod	M.U.
Ann	--	0.142	0.041	0.183
FO	0.072	--	0.082	0.224
Unmod	0.035	0.077	--	0.123

**Significant Difference*

(Standard Deviations shaded)

Table 3.22: MMD Results for the Inland Valley Group (FP-H)

	Ann	FO	Unmod	M.U.
Ann	--	0.277*	0.013	0.29
FO	0.065	--	0.114*	0.392
Unmod	0.066	0.056	--	0.127

**Significant Difference*

(Standard Deviations shaded)

These results demonstrate that ACM does not affect epigenetic trait incidence among Formative Period coastal groups. The results among Formative Period inland groups are different, however, in that fronto-occipital modification does affect epigenetic trait incidence relative to both annular modified and nonmodified crania.

3.2.1.6 Regional Development Period

The data were then examined for the Regional Development Period where only inland group data are available. Seven traits demonstrated statistically significant differences, all of which demonstrated no differences among the sexes. Therefore none of the traits were eliminated from the overall MMD analysis (Table 3.23).

Table 3.23: Traits Remaining After Data Reduction (Regional Development Period; Hrdlička Typology)

Inland Valley Group
Parietal Foramen (Left)
P. Condylar Canal (Right)
Coronal Ossicle (Right)
Parietal Notch (Left)
Maxillary Torus
Condylar Facet (Left)
Mylohyoid Groove (Left)

These traits were examined with the MMD, and the results of which demonstrated distance (or difference) was present among all three cranial forms (Table 3.24).

Table 3.24: MMD Results for Regional Development Period (Hrdlička Typology)

	Ann	FO	Unmod	M.U.
Ann	--	0.096*	0.077*	0.173
FO	0.039	--	0.077*	0.173
Unmod	0.034	0.017	--	0.154

**Significant Difference*

(Standard Deviations shaded)

These results demonstrate the both annular and fronto-occipital modification styles affect epigenetic trait incidence among Regional Development Period inland groups. Also, the epigenetic trait incidences are different between annular and fronto-occipital modification styles, suggesting that both styles affect epigenetic traits differently.

3.2.1.7 Late Period

The data were finally examined for the Late Period, and it, too, was divided into coastal and inland valley groups. When the epigenetic trait data of the coastal valley group (LP-H) were examined, a total of 7 traits demonstrated statistically significant differences among the three cranial forms, but only 3 traits remained after the traits were examined for differences by sex (Table 3.25). An examination of the epigenetic trait data of the inland valley group (LP-H) yielded 7 traits with statistically significant differences but two traits were eliminated due to differences by sex, leaving 5 traits that could be used for the MMD analysis (Table 3.25).

Table 3.25: Traits Remaining After Data Reduction (Late Period; Hrdlička Typology)

Coastal Valley Group *(LP-H)*	**Inland Valley Group *(LP-H)***
Supraorbital Foramen (Right)	P. Condylar Canal (Left)
Parietal Foramen (Left)	Divided Hypoglossal (Right)
Foramen Spinosum (Right*)	Accessory Infraorbital Foramen (Left* & Right)
Accessory Infraorbital Foramen (Right*)	Asterionic Bone (Left & Right)
Parietal Notch (Right)	Os Inca*
Maxillary Torus*	
Mylohyoid Groove (Left*)	

The results of the MMD analyses for the coastal and inland valley groups (LP-H) demonstrated slightly different results when compared to each other. The results for coastal valley group (LP-H) demonstrated no distance (or difference) between fronto-occipitally modified and unmodified crania, whereas the remaining cranial forms demonstrated distance (or difference) (Table 3.26). The results for inland valley group (LP-H) demonstrated no distance (or difference) between annularly modified and unmodified crania, and distance (or difference) among the remaining cranial forms (Table 3.27).

Table 3.26: MMD Results for Coastal Valley Group (LP-H)

	Ann	FO	Unmod	M.U.
Ann	--	1.462*	0.992*	2.454
FO	0.467	--	0.343	1.805
Unmod	0.274	0.274	--	1.336

**Significant Difference*

(Standard Deviations shaded)

Table 3.27: MMD Results for Inland Valley Group (LP-H)

	Ann	FO	Unmod	M.U.
Ann	--	2.265*	0.006	2.271
FO	0.46	--	1.641*	3.906
Unmod	0.085	0.468	--	1.647

**Significant Difference*

(Standard Deviations shaded)

These results demonstrate that among Late Period coastal groups that annular modification styles affected epigenetic traits relative to fronto-occipitally modified and unmodified crania, while among Late Period inland groups fronto-occipital modification styles affected epigenetic traits relative to annularly modified and unmodified crania. It was also demonstrated that annular and fronto-occipital modification styles affected epigenetic traits differently among both coastal and inland Late Period groups.

3.2.2 Cephalometric and Cranial measurements

3.2.2.1 Cephalometric Measurements (Modified and Unmodified Crania)

As mentioned previously, all unmodified and modified crania were traced using the Orthotrac software based on angular and linear measurements chosen by the author in consultation with Dr. Drew Smith. The Orthotrac software produced output that demonstrated the measurements (in millimeters or degrees) for each measurement or angle registered in the analysis, and these measurements were ultimately compared between modified and unmodified individuals, as well as by modification styles outlined in the Hrdlička typology and unmodified individuals.

The first analysis, comparing all modified (regardless of modification style) and unmodified individuals, was completed using the Student's T-test. The results of the Student's T-tests demonstrated that only one measurement, Nasion-Pogonion/Mandibular Plane, was statistically significantly different between modified and unmodified crania (Table 3.28). This is an angular measurement that notes the changes to the medial vertical angle of the anterior portions of the face, particularly in relation to the location of the mandible, and among modified individuals, there was a slight but significant increase in this measurement among modified individuals (Figure 3.1). There was one other measurement, Basion-Nasion, that approached significance. This is a linear measurement that measures the distance between basion and nasion, and there was a slight increase in this measurement among modified individuals. The remaining measurements demonstrated no statistically significant differences between modified and unmodified crania.

Table 3.28: Comparison of Modified and Unmodified Cranial Cephalometric Measurements (T-Test)

Cephalometric Measurements	T-test P-Value
Sella-Nasion-A-point (A)	.154
Sella-Nasion-Frankfort Plane (A)	.130
Sella-Nasion-Palatal Plate (A)	.282
Nasion-Sella-Gnathion (A)	.569
Sella-Nasion-PM Vertical (A)	.473
Sella-Nasion-Basion (A)	.340
Condylar Plane/Sella-Gnathion (A)	.174
Nasion-Pogonion/Mandibular Plane (A)	.007*
Anterior Nasal Spine-Nasion (L)	.114
Sella-Nasion (L)	.609
Basion-Nasion (L)	.096
Menton-Nasion (L)	.916

**Statistically Significant (P=0.05)*

These two measurements, Nasion-Pogonion/Mandibular Plane and Basion-Nasion, meet the expectations that there would be an increase in measurements among modified individuals, while the remaining measurements did not meet expectations. This increase is expected as ACM is believed to increase facial height and convexity as this is the most likely change that will occur to the face when modification (intentional or unintentional) occurs.

3.2.2.2 Cephalometric Measurements (Hrdlička Typology)

The analysis comparing the Hrdlička modification styles and unmodified individuals was completed using the ANOVA test. The results of this test demonstrated three measurements with statistically significant differences among the modification styles and unmodified crania (Table 3.29). These measurements included the Sella-Nasion-A-point, an angular measurement that measures the convexity of the face in relation to the location of the maxilla, Sella-Nasion-Basion, an angular measurement that examines the general convexity of the face, and Nasion-Pogonion/Mandibular Plane, which measures the medio-vertical angle based on the anterior portion of the face. Overall, there was no difference in the Sella-Nasion-A-point measurement between annularly modified and unmodified individuals, but fronto-occipitally modified individuals demonstrated a slight but significant increase for this measurement. Annularly modified individuals demonstrated a slight but significant decrease while fronto-occipitally modified individuals demonstrated a slight but significant increase in the Sella-Nasion-Basion measurement when compared to unmodified individuals. Individuals with annular or fronto-occipital modification demonstrated statistically significant increased measurements in the Nasion-Pogonion/Mandibular Plane measurement as compared to unmodified individuals.

Table 3.29: Comparison of the Hrdlička Typology and Unmodified Cranial Cephalometric Measurements (ANOVA)

Cephalometric Measurements	**ANOVA P-Value**
Sella-Nasion-A-point (A)	.032*
Sella-Nasion-Frankfort Plane (A)	.199
Sella-Nasion-Palatal Plate (A)	.389
Nasion-Sella-Gnathion (A)	.248
Sella-Nasion-PM Vertical (A)	.717
Sella-Nasion-Basion (A)	.015*
Condylar Plane/Sella-Gnathion (A)	.630
Nasion-Pogonion/Mandibular Plane (A)	.016*
Anterior Nasal Spine-Nasion (L)	.167
Sella-Nasion (L)	.140
Basion-Nasion (L)	.103
Menton-Nasion (L)	.334

**Statistically Significant (P=0.05)*

These results demonstrate that ACM does affect facial measurements. They do not, however, completely agree with the expectations. It was expected that both modification styles would increase the effected measurements, which occurred with the Nasion-Pogonion/Mandibular Plane measurement. Fronto-occipital modification caused an increase in the Sella-Nasion-A-point and Sella-Nasion-Basion measurements. Annular modification demonstrated a decrease in the Sella-Nasion-Basion measurement but no difference in the Sella-Nasion-A-point measurement. The differences in the results between the two ACM styles are most likely due to the pressures associated with the ACM devices. The increase in the measurements among the fronto-occipital modification style could be due to the pressures on the occipital, which would have pushed the sphenoid (sella) up, causing the face (nasion) to compensate accordingly when the facial growth occurred during adolescence. The pressures on the frontal and occipital bones associated with annular modification could have caused a decrease in measurements if the device lay low on the forehead, closer to the nose (nasion), causing the face to compensate accordingly.

3.2.2.3 Cranial Measurements (Modified and Unmodified Crania)

Following the analyses of the cephalometric measurements, the cranial measurements were examined in order to determine any differences noted among them between modified and unmodified individuals (and subsequently by modification style) in relation to the changes noted from the cephalometric measurements. When the cranial measurements were compared between modified and unmodified crania, only two measurements demonstrated statistically significant differences: bistephanic breadth and orbit height, although four measurements, total facial height, maximum frontal breadth, interorbital breadth, and malar length, approached significant differences (Table 3.30). On average, modified individuals demonstrated an increase in size for both bistephanic breadth and orbit height in comparison to unmodified individuals.

Table 3.30: Cranial measurements (Modified and Unmodified Crania)

Craniometric Measurement	P-value
Upper facial height	.524
Total facial height	.083
Maximum frontal breadth	.082
Minimum frontal breadth	.566
Bifrontal breadth	.913
Bistephanic breadth	.039*
Bizygomatic breadth	.276
Bimaxillary breadth	.742
Nasal height	.358
Nasal breadth	.812
Orbit height	.023*
Orbit breadth	.900
Interorbital breadth	.056
Biorbital breadth	.976
Bijugal breadth	.547
Palate breadth, external	.188
Palatal length, external	.267
Malar length, inferior	.294
Malar length, maximum	.077
Cheek height	.900

**Significant Measurement*

The increase in these two measurements does meet the overall expectation as it is believed that modification/change will increase facial height and convexity.

3.2.2.4 Cranial Measurements (Hrdlička Typology)

Further analysis of these measurements as divided by the Hrdlička typology demonstrated several more measurements with statistically significant differences among the three cranial forms, and these measurements included upper facial height, total facial height, maximum frontal breadth, external palatal length, inferior malar length, and maximum malar length (Table 3.31). Minimal frontal breadth and orbit height demonstrated differences that approached significance. On average, annularly modified individuals demonstrated an increase in size for upper facial height, total facial height, and external palate length and demonstrated a decrease in size for maximum frontal breadth, bistephanic breadth, inferior malar length, and maximum malar length as compared to unmodified individuals, whereas fronto-occipitally modified individuals demonstrated an increase in size for maximum frontal breadth and bistephanic breadth but a decrease in the upper facial height, total facial height, external palate length, inferior malar length, and maximum malar length.

Table 3.31: Cranial measurements (Hrdlička Typology & Unmodified Crania)

Craniometric Measurement	**P-value**
Upper facial height	.040*
Total facial height	.011*
Maximum frontal breadth	.000
Minimum frontal breadth	.079
Bifrontal breadth	.419
Bistephanic breadth	.100
Bizygomatic breadth	.564
Bimaxillary breadth	.298
Nasal height	.234
Nasal breadth	.877
Orbit height	.062
Orbit breadth	.403
Interorbital breadth	.154
Biorbital breadth	.727
Bijugal breadth	.440
Palate breadth, external	.215
Palatal length, external	.006*
Malar length, inferior	.043*
Malar length, maximum	.023*
Cheek height	.168

**Significant Measurement*

Overall, some of these results meet the expectations that modification (in generally) will increase facial measurements. Annularly and fronto-occipitally modified crania demonstrated an increase in half of these measurements, but they caused different changes in the facial bones.

3.3 Discussion

3.3.1 Epigenetic Traits

There appears to be no difference in epigenetic traits that will affect biological distance studies when modified (all modification styles lumped together) and unmodified crania are compared based on the results of the epigenetic trait analysis through the MMD analysis. This result is in agreement with studies by Anton *et al.* (1992), Dingwall (1931), El Najjar and Dawson (1970), Gottlieb (1978), Konigsberg *et al*. (1993), O'Loughlin (2004), and Wilczak and Ousley (2009) that found the same or similar results (see Chapter 2).

When the modified and unmodified cranial data were divided by period and geographical region, however, the MMD analysis demonstrated a consistent trend of differences in epigenetic trait incidence between coastal valley groups regardless of period and the inland valley groups of the Regional Development Period. These results suggest that for these periods/groups that epigenetic trait incidence and frequencies are different between modified and unmodified individuals, a result supported by previous studies by Cilento (1921), Dorsey (1897), Gerszten (1993), Guillen (1992), McGibbon (1912), Oetteking (1930), Ossenberg (1970), and White (1996). This result appears to falsify the null hypothesis.

Further division of all of the data by the Hrdlička typology demonstrates distance (or difference) exists between the modified cranial styles when tested with the MMD analysis: annular and fronto-occipital modifications, annularly modified and unmodified crania, and fronto-occipitally modified and unmodified crania. This result suggests that specific ACM styles do affect epigenetic traits. When the data are more closely analyzed, the expectations of changes produced by annular and fronto-occipital modification are not always met, although the results differ by region and period. Specific information pertaining to these changes can be found in Tables 3.32-3.36.

Table 3.32: Expectations & Results for the Formative Period: Coast

Epigenetic Trait	Expectation Annular Modification	**Result**	Expectation Fronto-occipital Modification	**Result**
Coronal Ossicles	Increase	**Increase**	Decrease	**Decrease**
Sagital Ossicles	Decrease	**No Change**	Increase	**No Change**
Lambdoidal Wormian Bone	Increase	**Increase**	Decrease	**Increase**
Occipit-Mastoid Wormian Bone	Increase	**Increase**	Decrease	**Decrease**
Bregmatic Bone	Increase	**No Change**	Decrease	**No Change**
Lambdoid Bone	Decrease	**Decrease**	Increase	**Increase**
Asterionic Bone	Increase	**Increase**	Decrease	**Increase**
Parietal Notch	Increase	**Increase**	Decrease	**Decrease**
Os Inca	Decrease	**Increase**	Increase	**No Change**

Table 3.33: Expectations & Results for the Formative Period: Inland

Epigenetic Trait	Expectation Annular Modification	**Result**	Expectation Fronto-occipital Modification	**Result**
Coronal Ossicles	Increase	**Decrease**	Decrease	**Decrease**
Sagital Ossicles	Decrease	**Increase**	Increase	**No Change**
Lambdoidal Wormian Bone	Increase	**Decrease**	Decrease	**Decrease**
Occipit-Mastoid Wormian Bone	Increase	**Increase**	Decrease	**Increase**
Bregmatic Bone	Increase	**No Change**	Decrease	**No Change**
Lambdoid Bone	Decrease	**Increase**	Increase	**Increase**
Asterionic Bone	Increase	**Decrease**	Decrease	**Decrease**
Parietal Notch	Increase	**Decrease**	Decrease	**Decrease**
Os Inca	Decrease	**Increase**	Increase	**No Change**

Table 3.34: Expectations & Results for the Regional Development Period: Inland

Epigenetic Trait	Expectation Annular Modification	**Result**	Expectation Fronto-occipital Modification	**Result**
Coronal Ossicles	Increase	**Decrease**	Decrease	**Decrease**
Sagital Ossicles	Decrease	**Increase**	Increase	**Decrease**
Lambdoidal Wormian Bone	Increase	**Decrease**	Decrease	**Increase**
Occipit-Mastoid Wormian Bone	Increase	**Decrease**	Decrease	**Increase**
Bregmatic Bone	Increase	**No Change**	Decrease	**No Change**
Lambdoid Bone	Decrease	**Decrease**	Increase	**Decrease**
Asterionic Bone	Increase	**No Change**	Decrease	**Decrease**
Parietal Notch	Increase	**Decrease**	Decrease	**Decrease**
Os Inca	Decrease	**Increase**	Increase	**Decrease**

Table 3.35: Expectations & Results for the Late Period: Coast

Epigenetic Trait	Expectation Annular Modification	**Result**	Expectation Fronto-occipital Modification	**Result**
Coronal Ossicles	Increase	**No Change**	Decrease	**No Change**
Sagital Ossicles	Decrease	**No Change**	Increase	**No Change**
Lambdoidal Wormian Bone	Increase	**Decrease**	Decrease	**Increase**
Occipit-Mastoid Wormian Bone	Increase	**Decrease**	Decrease	**Increase**
Bregmatic Bone	Increase	**No Change**	Decrease	**No Change**
Lambdoid Bone	Decrease	**Increase**	Increase	**Decrease**
Asterionic Bone	Increase	**Decrease**	Decrease	**Increase**
Parietal Notch	Increase	**Increase**	Decrease	**Decrease**
Os Inca	Decrease	**No Change**	Increase	**No Change**

Table 3:36: Expectations & Results for the Late Period: Inland

Epigenetic Trait	Expectation Annular Modification	**Result**	Expectation Fronto-occipital Modification	**Result**
Coronal Ossicles	Increase	**Increase**	Decrease	**Decrease**
Sagital Ossicles	Decrease	**Decrease**	Increase	**Decrease**
Lambdoidal Wormian Bone	Increase	**Increase**	Decrease	**Decrease**
Occipit-Mastoid Wormian Bone	Increase	**Decrease**	Decrease	**Decrease**
Bregmatic Bone	Increase	**No Change**	Decrease	**No Change**
Lambdoid Bone	Decrease	**Decrease**	Increase	**Decrease**
Asterionic Bone	Increase	**Decrease**	Decrease	**Increase**
Parietal Notch	Increase	**Decrease**	Decrease	**Decrease**
Os Inca	Decrease	**Decrease**	Increase	**Decrease**

These results conflict with each other and lead to differing conclusions. It appears that how the data is treated will directly affect the results produced. Combining different modification styles into a single, undifferentiated "modified" sample will mask patterns of variability expressed by each style, whereas separating the data by modification styles will demonstrate the effects of each ACM style on epigenetic traits, as was noted in Table 3.19 with the Hrdlička typology. This study, however, did not take into account individual variations of ACM styles beyond this typology and how they may affect the results. A preliminary analysis not presented here demonstrated a decrease in the number of traits affected as the data was further divided the Dembo-Imbelloni (1938) and Allison *et al.* (1981) typologies, but this analysis atomized the sample sizes and therefore produced statistically weakened results. This lumping of ACM style variability could, in part, account for the discrepancies in the literature concerning the effects of ACM on epigenetic traits, particularly when studies utilize the same or genetically and temporally similar samples. Further research with larger samples should be completed in order to determine if variations of ACM styles in more complex typologies cause differences in epigenetic trait incidence and frequency.

Another explanation is that the differences in epigenetic trait frequencies among modified and unmodified individuals could be related to the number of traits surveyed and sample sizes for each analysis. While it is recommended that all epigenetic traits undergo a data reduction process prior to MMD analysis, there is a minimum number of epigenetic traits that should be utilized in these analyses (Molto pers comm., 2012). This minimum number is not readily available in the literature, but according to Molto (pers comm., 2012), at least 15 traits should be utilized in an MMD analysis. Unfortunately, due to the lack of statistically significant differences between modified (lumped and separated) and unmodified individuals produced in the G-test, this minimum number of traits could not be met. Furthermore, the further atomization of the data due to differences in sex, trait correlation, geographical region, site, and period further reduced the sample sizes for each analysis with the most individuals surveyed in a single analysis being 167 (Regional Development Period inland valley group) and the least being 26 (Late Period coastal valley group). A combination of decreased sample sizes and traits utilized in the MMD analyses could cause false statistical significance or not identify true statistical significance within groups, skewing and providing inaccurate results. Unfortunately, larger sample sizes were not available for this study, and the results herein are the best that could be reached given the circumstances. I believe that reduced sample sizes, particularly when the data were further atomized by typology, definitely played a role in the results and accounts for the differences in results between modified and unmodified crania and the Hrdlička typology.

In conclusion, annularly and fronto-occipitally modified crania do affect epigenetic traits differently, but the differences noted between these two styles cancel each other out when they are lumped together, a conclusion that does not negate the previous one. Therefore, if modified crania from northern Chilean groups are lumped together, the differences between the two styles will not be discernable due to statistical noise obscuring the patterns of both modification styles. Therefore, studies utilizing epigenetic traits should not ignore the effects of ACM on the data and ACM styles should not be lumped together as they obscure patterns occurring in the data.

3.3.2 Facial Measurements

Overall, these results demonstrate that ACM does affect some facial measurements but not all. This is an incomplete rejection of the null hypothesis. This result is in agreement with previous analyses that also noted some facial change occurred in ACM crania (e.g. Anton, 1989; Bjork and Bjork, 1964; Brown, 1981; Cheverud *et al.*, 1992; Cybulski, 1975; Kohn *et al.,* 1993; Manriquez *et* al., 2006; Oetteking, 1930; Pomeroy *et al.,* 2010; Rhode and Arriaza, 2006; Rogers, 1975; Schendel *et al.*, 1980) but particularly with Anton (1989), Brown (1981), Cheverud *et al.* (1992), Cybulski (1975), Oetteking (1930), Rhode and Arriaza (2006), Rogers (1975), Schendel *et al.* (1980) who noted similar facial measurement changes found in this study, in the modified crania they surveyed (see Chapter 2).

The expectation that ACM would affect facial convexity and vertical height, however, was not met, as the cephalometric analyses demonstrated that overall there were not enough facial measurement and angular changes produced that would have greatly affected either convexity or height (Table 3.37). The cephalometric measurements did demonstrate some slight and statistically significant changes in height and convexity, evidenced by the three (out of 12) measurements that were affected when using the Hrdlička typology. As the remaining measurements were not affected, however, the few facial metric changes induced by ACM were not great enough to completely change the whole of the face. Further analysis of the cranial measurements further supports this latter point about partial facial change as the facial alterations are primarily found on the frontal bone and orbits but also found in the zygomatic bones, maxilla, and mandible. These craniometric changes are similar to those noted in the cephalometric analyses as both changes occur in the same facial areas.

Table 3.37: Expectations and Results (Cephalometric Measurements)

Measurement	Expected Change	Expectation Met (Mod/Unmod)	Expectation Met (Hrdlička Typology)
Sella-Nasion-A-point (A)	Increase	No	Yes
Sella-Nasion-Frankfort Plane (A)	Increase	No	No
Sella-Nasion-Palatal Plate (A)	Increase	No	No
Nasion-Sella-Gnathion (A)	Increase	No	No
Sella-Nasion-PM Vertical (A)	Increase	No	No
Sella-Nasion-Basion (A)	Increase	No	Yes
Condylar Plane/Sella-Gnathion (A)	Increase	No	No
Nasion-Pogonion/Mandibular Plane (A)	Increase	Yes	Yes
Anterior Nasal Spine-Nasion (L)	Increase	No	No
Sella-Nasion (L)	Increase	No	No
Basion-Nasion (L)	Increase	No	No
Menton-Nasion (L)	Increase	No	No

There was an expectation for a greater number of changes to be present in modified individuals, and the reasons for the lack of changes may be related to the genetic nature of craniofacial growth or growth relapse. As described by Moss (1960, 1962, 1969), craniofacial growth is hypothesized to be managed by both soft tissue and osseous tissue growth, and both genetic and environmental factors control overall growth. It may be that while ACM is an environmental factor that can redirect growth, this redirection may be strongest in areas of device placement and only indirectly affect the peripheral areas (e.g. cranial base and face). The timing at which ACM devices were removed (perhaps as late as the fifth year of life) may be too early to affect permanent changes in the peripheral area of the face, particularly since the face undergoes rapid growth during late childhood and puberty (approximately 7 or more years later). This lag between the removal of the ACM devices and rapid facial growth may be enough time for the remaining areas of the skull, particularly the cranial base that dictates location of many facial features, to relapse (change and be redirected) to their intended, unmodified locations (Thilander, 2012). It may be that if permanent facial changes related to ACM were caused that it was due to longer device placement or direct placement on the facial bones being affected. Further study into this matter, particularly among populations with longer timings for their modification practices (e.g. European groups) (Dingwall, 1931), is necessary to further test this hypothesis.

Regardless of why there are fewer facial alterations than expected, there do remain alterations to the face, and these alterations are statistically significant and warrant further review in relation to their effect on biological affinity studies on northern Chilean groups. Utilizing multivariate analyses (most likely factor analysis), Cocilovo (1975) identified ten facial measurements that are largely "unaffected" by ACM, including basion-prosthion length, palatal length and breadth, upper facial height, minimum frontal breadth, nasal height and breadth, orbital height and breadth, and bizygomatic breadth. The results of this analysis confirm that three of these measurements, palatal length, upper facial height, and orbital height, are affected among northern Chilean populations and therefore cannot be used within the context of biological affinity studies. This result is in part supported by Rhode and Arriaza (2006) who demonstrated that several of the "unaffected" measurements identified by Cocilovo (1975) were affected by ACM, but the results between the cranial measurements of the present study and the one produced by Rhode and Arriaza (2006) also differ slightly. Both studies note changes in the same bones but with different measurements. Also, Rhode and Arriaza (2006) note the majority of the facial changes appear to be located in the periphery of the face, whereas the majority of the facial changes noted in this study are in the center of the face. The discrepancy in results is most likely due to differences in methods, as their study only used osteometric analyses, whereas this study used both cephalometric analyses and osteometric analyses of the cranial changes focusing on the measurements of the center of the face. In addition, the two studies used slightly different samples. These results demonstrate that ACM does affect the facial bones, albeit in variable ways, and scholars should take care in using facial metrics in biological affinity studies that include individuals demonstrating ACM.

3.4 Conclusion

The purpose of this study was to determine the effects of ACM on cranial epigenetic traits and facial measurements in order to determine if and how ACM may affect biological affinity studies. The results of this analysis demonstrate that ACM styles will affect epigenetic traits differently and in relation to the devices and pressures associated with the creation of the final cranial form. Lumping of ACM styles into one broad category is not recommended as it masks patterns of changes associated with specific

ACM styles. Also, some facial measurements can and will be affected by ACM and therefore scholars should carefully scrutinize the facial measurements chosen before completing analyses using these traits. Overall, the specific results of this study are only applicable to the populations and samples utilized within this analysis, but the variability in the literature on this topic should be used a cautionary tale to scholars to carefully scrutinize their methods and results to ensure maximum accuracy.

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Chapter 4

4 Love You to Death: An Investigation of Artificial Cranial Modification, Morbidity, and Mortality

The region of the Andes in South America demonstrates several millennia of human occupation due in part to unique environmental conditions that allow specially adapted flora, fauna, and human groups to thrive, despite what many consider harsh environmental conditions from the dry, arid deserts that exists along the South American coastline (Moseley, 2001). These deserts are some of the driest in the world, which can make living difficult, but they do provide optimal conditions for the preservation of organic materials, including human skeletal remains and mummified tissues. The preservation of these tissues enables scholars to study many aspects of ancient humans, particularly paleopathology, the study of disease (Gerszten *et al.*, 2007). Scholars have an approximately 8,000 year time span over which to study disease among the ancient Andean populations, allowing not only for the identification of specific diseases that plagued these groups but also the study of the evolution of these diseases (Verano, 1997a).

The study of ancient diseases and conditions among ancient Andean groups has been exhaustive, but new avenues of research continue to be introduced. One of the most recent identifications concerns the pathological consequences of artificial cranial modification (ACM). Recently, studies by Guillen *et al.* (2009) and Mendoca de Souza *et al.* (2008) identified the cultural practice of artificially modifying the skull as having lethal consequences for at least 3 juveniles, an assertion suggested by at least one ethnohistorian (Diez de San Miguel, 1964 [1567]). These scholars identified several pathological conditions, including porotic lesions and periostitis on the cranial bones, as evidence to support their claims, but other diseases (e.g. scurvy or rickets) may cause these same conditions. Furthermore, the small sample size in these studies and proliferation of ACM practices world-wide does call into question the overall frequency of deaths primarily caused by ACM. The purpose of this study is to explore the effects of ACM on morbidity and mortality patterns of individuals within a larger sample in order to determine the prevalence of ACM related deaths.

Scholars have already identified many diseases and conditions that were present among Andean groups. Infectious diseases such as pneumonia (Arriaza *et al.*, 1995; Aufderheide, 2000; Aufderheide *et al.*, 2002 & 2008; Lombardi, 2001), Carrion's disease (Allison *et al.*, 1974a; Moodie, 1923; Schultz, 1968), tuberculosis (Allison *et* al., 1981a; Arriaza *et al.*, 1995; Extberria *et* al, 2000; Fernando Martinez *et al.*, 2010; Lombardi, 2001; Lombardi and Caceras, 2000; Salo *et al.*, 1994), and treponemial infections (Allison *et* al., 1982; Lory and Aguade, 2000; Rothschild and Rothschild, 1996; Standen *et al.*, 1984; Standen and Arriaza, 2000a) were common among Andean groups from all areas and periods. Other conditions, however, are believed to have been geographically and temporally specific: Chagas' disease is attributed to agricultural groups but is found across the Andean landscape (Aufderheide, 2000; Aufderheide *et al.*, 2005; Guhl *et al.*, 1999; Rothhammer *et al*., 1985); Leishmaniasis is believed to have been, just as it is today, a disease of highland inhabitants (Costa *et al.*, 2009; Marsteller *et al*., 2011; Weiss, 1961); and coastal groups demonstrate high frequencies of marine parasitic infestations, attributed to the consumption of raw or undercooked seafood (Allison *et al.*, 1974b; Arriaza, 1995; Aufderheide *et al.*, 2002; Verano, 1997a). There are several other pathological conditions identified among ancient Andean groups, including cancers (Baraybar and Shimada, 1993; MacCurdy, 1923; Rosada and Vernacchio-Wilson, 2006; Verano, 1997b), infections (Rosada and Vernacchio-Wilson, 2006; Verano, 1997a), traumas (Rosada and Vernacchio-Wilson, 2006; Verano, 1997a), arthritis (Rosada and Vernacchio-Wilson, 2006; Standen *et al.*, 1984 & 2010; Verano, 1997a), and lesions (e.g. caries and porotic hyperostosis) associated with poor nutritional health (Blom *et al.*, 2005; Hrdlička, 1914; Lanfranco and Eggers, 2010; Merbs, 1992; Ortner, 2003; Rosada and Vernacchio-Wilson, 2006; Ubelaker, 1992; Weiss, 1961). It is believed that these groups resorted to various means to relieve pain associated with these various conditions as evidenced by the practices of coca consumption (Hanna, 1974; Indriati and Buikstra, 2001), trephination (Gerszten *et al.*, 1998; Verano, 1997a), and purposeful limb amputations (Verano *et al*., 2000).

The health status of ancient northern Chilean groups residing in the coastal deserts of the Atacama Desert in the Tarapaca region, the area of focus for this research, do not differ greatly from the overall Andean pattern of ancient pathological conditions. In addition, these groups also suffered from several other conditions, including chronic arsenic poisoning (Arriaza, 2005), complications associated with childbirth (Arriaza *et al*., 1988), melorheostosis (thickening of the cortical bone) (Kelley and Lytle, 1995), osteochondritis (loose bone in the knee or hip joint) (Kothari *et al.*, 2009), and osteoporosis (Arriaza, 1995; Kelley and Lytle, 1995). The diseases and conditions were found among all groups of varying social complexity and geographical distributions, and many continue to plague modern Andean populations today.

The literature concerning these pathological conditions is quite extensive, in part because the identification of many of these conditions among these populations, such as tuberculosis and treponemal infections, is scrutinized and debated. Much of the debate stems from the methods employed by scholars as many utilize macroscopic identification of osseous lesions to recognize specific pathological conditions. One of the primary limitations with this method is that bone reacts in a finite number of ways to pathological conditions (Ortner, 2003), requiring scholars to use multiple lines of evidence to support their identification of specific diseases and conditions. Furthermore, many of these fail to address the "Osteological Paradox" (Wood *et al.*, 1992), which faults studies for assuming ancient populations are static entities with similar risk factors for disease, as well as faulting scholars for not acknowledging the obvious: the bias of studying the deceased. While early studies for the most part did not and could not address many of these criticisms for several reasons, more recent studies are beginning to take these factors into account by addressing them in their investigations and interpretations of the data (c.f. Blom *et al.*, 2005; Costa *et al.*, 1997). These limitations will also be addressed herein for this investigation of the biological consequences of ACM.

4.1 Literature Review: Artificial Cranial Modification

Artificial cranial modification, also known as artificial cranial deformation, is the manipulation of the cranial vault through the use of externally applied forces in order to change the natural form of the skull (Anton and Weinstein, 1999; Gerszten, 1993; Perez, 2007). ACM was practiced in various cultures around the world for thousands of years and continues albeit rarely in some forms today (Dingwall, 1931; FitzSimmons *et al.*, 1998). Two broad types of ACM have been identified in the literature: intentional and unintentional modification (Dingwall, 1931; Flowers, 1881; Rogers, 1975). Intentional modification timing varied cross culturally, lasting from one to five years (Cieza de Leon, 1984 [1553]; de la Vega, 1966 [1609]; Diez de San Miguel, 1964 [1567]; Dingwall, 1931; de Landa, 1975 [1524-1579]; Morton, 1839; Torquemada, 1995; Weiss, 1961). The practice of intentionally modifying the skull has been widely studied over the past century.

Scholars also associate ACM with several biological and morphological changes to the skull (Anton and Weinstein, 1999; Dean, 1995; Gerszten, 1993; Holliday, 1993; O'Loughlin, 1996). Early studies noted that changes in skull morphology existed in modified crania (Blackwood and Danby, 1955; Dorsey, 1897; Moss, 1958), but these failed to explain the exact changes which occurred. Subsequent studies revealed areas and types of cranial shape change, identifying changes to the cranial base (Anton, 1989; Bjork and Bjork, 1964; Cheverud *et al.*, 1992; Frieß and Bayloc, 2003; McNeill and Newton, 1965; Moss, 1958; Oetteking, 1924), cranial vault (Cheverud *et al.*, 1992; Kohn *et al.*, 1993 & 1995; McNeill and Newton, 1965), and face (Anton, 1989; Anton and Weinstein, 1999; Bjork and Bjork, 1964; Brown, 1981; Cheverud *et al.*, 1992; Cybulski, 1975; Frieß and Bayloc, 2003; Kohn *et al.*, 1993 & 1995; Manriquez *et al.*, 2006; Oetteking, 1930; Pomeroy *et al.*, 2010; Rhode and Arriaza, 2006; Rogers, 1975; see Chapters 2 and 3). Scholars attribute these differences to several factors, including but not limited to population genetics, nutrition, and environment, as well as methodological differences among the studies (Cheverud *et al.*, 1992; Cocilovo *et al.*, 2011; Kohn *et al.*, 1993).

Scholars also acknowledge that other biological consequences, such as premature suture closure, endocranial shape changes, and bone necrosis, are directly or indirectly related to ACM. Premature suture closure, or craniosynostosis, has been noted in several different, geographically distant populations (Allison *et al.*, 1981; Anton and Weinstein, 1999; Gerszten, 1993; Gerszten and Gerszten, 1995; Holliday, 1993; O'Loughlin, 2004; Posnansky, 1957; White, 1996). Studies on the effects of premature cranial suture closure demonstrate increased intracranial pressure, distorted brain growth, mental retardation, seizures, blindness, developmental delays, epilepsy, nerve abnormalities, and other conditions are common, but it is unclear if these consequences are directly related to premature suture fusion alone or the underlying cause associated with premature suture fusion (Camfield *et al.*, 2000; Sgouros, 2005; van der Meulen *et al.*, 1990).

Endocranial shape change and bone necrosis are additional and unforeseen consequences associated with cranial modification. Some studies have noted that endocranial shape changes occur primarily in the sinuses and meningeal vessels (Dean, 1995; O'Loughlin, 1996), but other studies have noted significant endocranial changes in the entirety of the skull corresponding to ectocranial changes (MacLellan, 2006). These endocranial changes are most likely to produce discomfort and pain, the degree to which is dependent on the amount and type of alteration incurred by these areas. Bone necrosis is most often found in and around the spaces occupied by the deformation device (Allison *et al.*, 1981; Broca, 1879, cited in Guillen, 1992; Gerszten, 1993; Gerszten and Gerszten, 1995; Guillen, 1992; Holliday, 1993; Posnansky, 1957), and is often found in conjunction with ischemic ulcers as well as bacterial, fungal, and parasitic infections. These latter consequences are likely the result of improper hygienic control of the soft tissues impinged on by the deformation device (Holliday, 1993).

Most of these consequences are generally considered to be relatively minor and are not believed to significantly affect the overall health of modified individuals, despite Diez de San Miguel (1964 [1567]) suggesting otherwise, but recently scholars have reevaluated these effects and suggested that they could be lethal in some cases (Guillen *et al.*, 2009; Mendoca de Souza *et al.*, 2008). Mendoca de Souza *et al.* (2008) reported that an ancient

Peruvian infant whose cranium was modified exhibited an abundance of ecto- and endocranial bone necrotic lesions on the cranial vault. Studies of these lesions ruled out causal conditions such as anemia, scurvy, rickets, and other conditions, leading the scholars to conclude that cranial modification was the cause of the lesions and may have resulted in the premature death of the infant. A year later, Guillen *et al.* (2009) reached a similar conclusion when they examined the premature deaths of two juveniles from ancient Peruvian contexts. These individuals exhibited both ecto- and endocranial necrotic lesions, premature suture closure, and evidence of intracranial hematomas. These pathological lesions and conditions were eventually identified as complications from cranial modification and were also considered to have hastened these individuals' deaths. This conclusion calls into question the benign nature of ACM since it appears to have increased morbidity and possibly mortality and could demonstrate the importance of cultural norms and values within groups.

4.2 Literature Review: Osteological Paradox

The "Osteological Paradox" caused scholars in the discipline of Physical Anthropology, particularly paleodemographers and paleoepidemiologists, to critically evaluate some of the widespread assumptions about past populations and the methodologies employed from which these assumptions were derived (Wood et al. 1992). The main argument of the Osteological Paradox was that there are fundamental problems with accurately interpreting the osteological record for the purposes of understanding both human biological and cultural adaptation. They identified three main problems which had been previously overlooked: *demographic nonstationarity of the population*, *hidden heterogeneity in risks of individuals within the population*, and *selective mortality within a population*.

Each of these problems was detailed by Wood *et al.* (1992). *Demographic nonstationarity of a population* acknowledges that any population, from ancient to modern, is not a static entity. Population size can and will vary over time due immigration into and migration from the primary population, changes in mortality rates, and differential fertility rates. Wood *et al*. (1992) faulted paleodemographers for not adequately addressing these issues in their research projects. They believed that any further research should control for this problem, otherwise there would be a diminishment in the accuracy of future paleodemographic assessments. The authors called on new and improved methodologies to be created as a necessity to remedy this issue.

The second problem identified is known as *hidden heterogeneity in risks*. This presents the idea that populations are made up of individuals with a range of susceptibility or robusticity for or against disease pathogens, nutritional deficiencies, and mortality. An individual's risk factors to disease are affected by the individuals' genetic make up, social class (and, in turn, accessibility to resources), environment, and health over time. The authors argued that as individual risk level cannot be accurately accessed that no general conclusions about population health can be accurately assessed. Wood *et al*. (1992) drew upon an example of a fictional cemetery population with three different types mini populations demonstrating different risk levels: Group A was exposed to a disease and never experienced biological stress; Group B was exposed to the disease, became biologically stressed, lesions imprinted on their bones, but they survived the disease and died later; and Group C was exposed to the disease and died immediately, leaving no traces of the disease on bone. Upon excavation of the cemetery researchers may conclude that only one group (Group B) was exposed to the disease based on the evidence on their bones despite the entire cemetery population being exposed but demonstrating differential effects to the disease. This assessment would lead to inaccurate conclusions about the cemetery populations' general health due to improper analysis of the evidence. The authors instead proposed that lesions were not necessarily indicative of unhealthy individuals but instead could signify survivors whose superior health enabled them to endure and outlive those who died prior to disease processes imprinting on their bones. They argued that paleopathologists should consider this concept in their analyses and subsequent interpretations of the populations under their study.

Selective mortality within a population states that a fundamental problem with all osteological based research is that it involves the study of deceased individuals in a population, thus creating a bias in the sample. This bias is caused by the individuals in each age cohort being deceased, probably because they were too weak to survive, and therefore, the information provided on their skeletal remains may not carry accurate information about the health status for that age cohort or the remainder of the population. The authors refer back to their previous example about differential lesion incidence from similar disease exposures. They caution that individuals with more lesions may have been survivors of multiple disease onslaughts but would be interpreted as the weakest of the population, skewing the interpretations of the population's general health.

Wood *et al*. (1992) do admit, however, that one cannot be completely certain as to what the normal distribution of lesions should be within any past population without knowing its average frailty index. They draw upon the example of the Oneota sample: the Oneota had many young children who had a high prevalence of porotic hyperostotic lesions, while older children and adults had lower prevalence of these same lesions. They argue that older children and adults may have had similar prevalence of porotic hyperostotic lesions to the young children at one point (early childhood), but time allowed them to heal and no longer accurately depict their overall health throughout time. The inverse can also be true, however, in that the frail (who had many lesions) died young, and the survivors are individuals who did not have many or any lesions imprinted on their bones. Analyses of the older individuals without taking into account the possibility of time and healing could lead to mistaken interpretations about the overall population's health.

4.3 Materials and Methods

A sample of 506 ancient Chilean individuals housed at El Museo Arqueologico de San Miguel de Azapa, Arica, Chile, was surveyed for this study. The sample was made up of modified and unmodified adults and juveniles from both coastal and inland contexts from three northern Chilean valleys: Azapa, Camarones, and Lluta. It is also acknowledged that biological differences in the sample may also exist, although that is debated (see Moraga *et al.*, 2005; Rothhammer *et al.*, 2002; Sutter, 2000, 2005, 2006; Sutter and Mertz, 2004; Varela and Cocilovo, 2002). These samples were lumped together despite being derived from geographically and temporally different contexts in order to increase sample size, and possible effects from the geographical and temporal differences will be addressed in the discussion. The individuals were also from various temporal periods spanning 9,000 years. One group of unknown temporal origin for inland Azapa Valley was also included since these individuals were modified and unmodified, well preserved, and found within the study area (Table 4.1).

Table 4.1: Sample Make Up

Site	Valley	Location	Culture	Period	# of Adults	# of Juveniles
Azapa 6	Azapa	Inland	Cabuza-San Miguel	Regional Development Period	29	8
Azapa 8	Azapa	Inland	Gentilar	Regional Development Period	24	3
Azapa 11	Azapa	Inland	San Miguel-Maytas	Regional Development Period	6	0
Azapa 70	Azapa	Inland	Alto Ramirez	Formative Period	21	3
Azapa 71	Azapa	Inland	Cabuza-Maytas	Regional Development Period	52	15
Azapa 75	Azapa	Inland	Alto Ramirez	Formative Period	30	14
Azapa 76	Azapa	Inland	San Miguel	Regional Development Period	7	4
Azapa 140	Azapa	Inland	Maytas	Regional Development Period	59	22
Azapa 141	Azapa	Inland	Cabuza-Chubal	Regional Development Period	14	1
Azapa 143	Azapa	Inland	Unknown	Unknown	10	3
Camarones 8	Camarones	Coast	Gentilar	Regional Development Period	11	7
Camarones 9	Camarones	Coast	Inca	Late Period	16	8
Camarones 15	Camarones	Coast	Faldas del Morro	Formative Period	9	0
Lluta 54	Lluta	Inland	Inca	Late Period	6	3
Morro 1	Azapa	Coast	Chinchorro	Archaic Period	28	3
Morro 1-6	Azapa	Coast	Chinchorro	Archaic Period	14	1
Playa Miller 7	Azapa	Coast	El Laucho	Formative Period	63	9
Quiani 7	Azapa	Coast	Quiani	Formative Period	4	0
				Total	403	104

Sex and age-at-death estimations were determined based on morphological traits of the cranium and teeth for both adults and juveniles as applicable. At the time of data collection, post-cranial remains were not available for study, allowing only cranial methods to be used to determine sex and age-at-death. Sex determinations were based on morphological traits of the cranium (e.g. nuchal crest, mental eminence, mastoid process) and mandible (e.g. mental eminence) and were scored for adults only (Acsadi and Nemeskeri, 1970; Buikstra and Ubelaker, 1994). Sex was not scored for juveniles since juvenile sexing techniques are considered unsuitable for this sample (Sutter, 2003).

Cranial methods for determining age at death were limited as suture closure techniques cannot be used to accurately judge age-at-death in modified adult or juvenile crania (O'Brien and Sensor, 2008). Age at death was determined based on dental formation standards only for juveniles. X-ray analyses of dental formation patterns were used to identify specific ages at death for juveniles (Ubelaker, 1999). As this method is inadequate for determining an age range at death for adults once the third molar is erupted, adults were simply classified as being over the age of 21. Adults could not be aged based on dental wear patterns due to insufficient dental material available for study at time of data acquisition, and suture closure aging methods could not be accurately employed due to the effects of ACM.

Cranial modification was also scored for each cranium based on a nested typology developed by the author (see Chapter 2). The Nested Typology combined three previously created modification typologies from Hrdlička (1912), Dembo and Imbelloni (1938), and Allison *et al*. (1981). All of the typologies were employed in order to examine difference among the typologies and allow for future comparison of the results of this study with the results of past and future studies conducted on northern Chilean modified crania. These past studies have each employed a different typology, making it difficult to compare their results. As well, the Nested Typology enables ease of comparison with future studies due to the various typologies employed. In this case, the nested typologies allow for ease of comparison of the results derived from this study and other similar studies (e.g. Gerszten, 1993; Guillen *et al*., 2009; Mendonca de Souza *et al.*, 2008).

Cranial modification styles were scored visually based on criteria described by the authors of the existing typologies. Crania were first scored as modified or unmodified before further actions were taken. If the cranium was unmodified, no further scoring took place. If the cranium was modified, modification style was determined based on morphological shape and evidence of device placement and secondarily on the cranial index. Crania were then scored based on the typologies used in the Nested Typology. The typologies in the Nested Typology were renamed based on their level of complexity. The simplest typology (Hrdlička, 1912) is Level 1, the next complex (Dembo and Imbelloni, 1938) is Level 2, and the most complex (Allison *et al*., 1981b) is Level 3. It is important to note that there was some difficulty scoring crania based on the Level 3 (Allison *et al*., 1981b) style and therefore these styles did not directly collapse into the simpler typologies as well as initially expected (see Chapter 2).

Pathological conditions were also scored as present or absent in each skull regardless of modification presence (Table 4.2). Previously identified pathological conditions related to ACM were scored to test the hypothesis that modification increased morbidity and mortality (Gerszten, 1993; Guillen *et al.*, 2009; Holliday, 1993; Mendoca de Souza *et al*., 2008). These conditions included necrotic lesions of the frontal, occipital, and endocranium, premature suture fusion, and craniosynostoses. Bone necrotic lesions of the cranium were identified as porous lesions on the skull in areas where the deformation device lay and increased pressures related to the modification process were present. These lesions, particularly in these locations, were identified as related to the deformation processes of ACM by Gerszten (1993), Guillen *et al.* (2009), Holliday (1993), and Mendoca de Souza *et al.* (2008). Premature suture fusions were identified as early closure of cranial sutures based on age of death of the individual. Suture closure is caused by several factors, including genetics, environmental factors (e.g. ACM), brain growth, muscle stresses, and the cessation of cranial growth (Gerszten, 1993; Hauser *et al.*, 1991; Sabini and Elkowitz, 2006). Based on these identified factors, it is believed that the pressures associated with ACM (be it cessation of cranial growth or redirection of brain growth) cause premature suture fusion. Due to the make up of the sample, identification of this lesion was made difficult given the lack of accurate age estimates in adults. Cranial sutures that demonstrated partial to complete closure were identified as premature suture fusions (Meindel and Lovejoy, 1985). Craniosynostoses in adults were identified by keeling (or upraised/pointed bone) along the locations of fully fused sutures in the absence of more specific information regarding longitudinal growth and suture fusion patterns for individuals surveyed (Ortner, 2003). The majority of the craniosynostoses were identified along the sagital suture but several were also identified along the metopic suture. Both premature suture fusions and craniosynostoses were chosen as diagnostic criteria based on a study by Gerszten (1993) who identified their relationship with ACM. These lesions taken together are herein referred to as "mechanical pathological lesions" due to their likelihood of being caused by the mechanical pressures of ACM and potential pathological consequences.

Additional conditions observed during data collection that could be related to modification were also noted, including thin bone, grooving, bumps, asymmetry, and indentations, which were scored as present or absent for the purpose of this research. Thin bone was identified through the shining of a light outside the cranial vault to observe light passing through rarified areas. Bumps were small bulges of bone of various shape and size that were believed to have been caused by ACM devices. Asymmetry was identified from the superior view of the skull and lop-sided appearance either in the frontal or posterior portion of the skull, believed to have been caused by the differential pressures of the deforming process. These lesions were included as it is believed that they were caused by rapid cranial growth and redirection of growth caused by ACM. Grooving was identified based on the unusual placement of channels on the cranial bones, usually located in areas of ACM device placement. Indentations were depressions in bone, often located at areas of the placement of specific ACM devices. These lesions were included to determine if and the extent to which they affected cranial growth by encouraging growth disturbances. These are herein referred to as "mechanical lesions" due to their association with cranial modification and the mechanisms associated with the pressures of modification. They may not necessarily lead to increased morbidity, however.

Porotic hyperostotic lesions of the parietal bones, cribra orbitalia, and dental enamel hypoplasia were also scored in order to determine if the other lesions may not be related to modification but another pathological condition or nonspecific biological stress. Porotic hyperostotic lesions are described as porous enlargements of the bone tissue, particularly on the cortical area (Ortner, 2003). Porotic hyperostotic lesions and cribra orbitalia (porotic lesions of the orbital roofs), found together or separately, are often associated with several different diseases, conditions, and stresses, including but not limited to anemia, scurvy, rickets, syphilis, trauma, infection, cancer, parasitic infestation, nutritional defeciency, and occasionally ACM, particularly among Andean groups (Blom *et al.*, 2005; El Najjar *et al.*, 1976; Gerszten, 1993; Holliday, 1993; Ortner, 2003; Ubelaker, 1992). Ortner (2003) states that porotic hyperostotic lesions associated with disease processes (e.g. anemia) often manifest as cribra orbitalia and/or lesions on the parietal bones and less often in other regions of the cranium. Dental enamel hypoplasia is defined as disturbances in the enamel of the teeth occurring during tooth development and is believed to be caused by stresses to the body such as nutritional deficiencies, illnesses, hereditary anomalies, psychological stress, and so on (Goodman and Rose, 1990; Hillson, 1996). Dental enamel hypoplasias are non-specific indicators of stress and are frequently used as a measure of developmental stress in populations (Goodman and Rose, 1990). Dental enamel hypoplasias manifest as pitting, furrowing, or grooving on the tooth crown, indicating a growth arrest during tooth development (Goodman and Rose, 1990; Hillson, 1996). It is easiest to identify these lesions on permanent incisor and canine teeth (Hillson, 1996). As there is no previously identified correlation between these lesions and ACM they were scored in order to determine if the remaining mechanical pathological and mechanical lesions were caused by another process (not ACM). These lesions are subsequently referred to as “stress indicators” to indicate their association with other pathological conditions which may or may not be related to cranial modification. Due to the nature of the sample employed for this study (several crania with teeth missing from antemortem loss or postmortem extraction), all permanent teeth in individuals aged 7 and older were surveyed and scored for the presence or absence of dental enamel hypoplastic lesions. While this method is not the optimal choice in scoring dental enamel hyplosias, it is an acceptable alternative when necessary (Goodman and Rose, 1990). They were all scored as present or absent as age categorization of these lesions could not be completed due to incomplete dentition and crania.

Table 4.2: Mechanical Lesions and Pathological Conditions Examined for this Study

Mechanical Pathological Lesions Associated with ACM	**Mechanical Lesions Possibly Associated with ACM**	**Stress Indicators Associated with Other Conditions**
Bone Necrosis of Occipital Bone	Thin Bone	Porotic Hyperostotic Lesions of Parietal Bone
Bone Necrosis of Endocranium	Grooving	Cribra Orbitalia
Bone Necrosis of Frontal Bone	Bumps	Dental Enamel Hypoplasia
Premature Suture Fusion	Asymmetry	
Craniosynostosis	Indentations	

Radiographs were taken of each skull for two purposes: 1) to accurately determine age at death for juveniles, and 2) to locate additional pathological conditions associated with cranial modification. X-rays were taken on Kodak T-Mat G/RA Diagnostic Film using a Shimadzu EZY-RAD VA-125P-CH X-ray machine. X-rays were taken by Dr. Carlos Ubeda, Mayorie Chandia, Mariel Gonzalez, and the author at the museum. Film development was completed at the museum by Mayorie Chandia and Mariel Gonzalez. Analysis of the X-rays was done by the author at the University of Western Ontario.

Statistical analyses of the data consisted of the G-test and Chi-square test. The G-test was undertaken using the PASW 18 (formerly SSPS) statistical suite, as well as a row by column test using Chi-Square (www.statstools.net). The G-test was employed in order to determine if and what specific pathological conditions were statistically significantly associated with specific cranial forms for each typology. The row by column test, using Chi-square as a test of independence that examines the proportions of connected data (in this case, incidence of pathological lesions by ACM type), was used in order to determine their associations. Data were divided into two types: adults (ages 21+) only data and juvenile (ages under 21) only data.

4.4 Hypotheses

Hypothesis testing was undertaken in order to determine if cranial modification negatively affected morbidity and mortality. The expectations were that modified individuals would demonstrate more incidences of the negative effects associated with modification (as seen in Table 4.2) in comparison to the unmodified individuals (Table 4.3, Expectation 1). Furthermore, the incidences of these pathological conditions by the various modification types in each typology were examined in order to determine if one type or a set of types presented with a higher incidence of the negative consequences (Table 4.3, Expectation 2). If this occurred, this could be indicative of one or more modification types and variants having a more hazardous effect on healthy living versus others. As part of this line of testing, there was an expectation that annular, annular oblique, annular erect, and styles 2, 3, 4, 11, and 12 (see Chapter 2) would exhibit higher incidences of specific conditions, including occipital bone necrotic lesions, premature suture fusion, sutural keeling, and slight asymmetry due to the location and associated pressures of their modification devices (Figure 4.1). Fronto-occipital modifications (fronto-occipital, fronto-occipital erect, fronto-occipital forward, fronto-occipital reverse, and styles 5, 6, 7, 8, 9, 10, 13, 14, 15), however, would exhibit both occipital and frontal bone necrotic lesions, premature suture fusion, sutural keeling, and slight to extreme asymmetry due to the location and associated pressures of their modification devices (Figure 4.2). The division of the data by ACM style would also be helpful in discerning *hidden heterogeneity in risks* among individuals in this sample since ACM styles are believed to be imbued with specific social meanings, particularly social status or ethnicity among Andean groups. Differential access to resources based on these social identities may cause differential health levels and corresponding pathological effects to be present in the cranium. Therefore, lesions present by ACM style may be indicative of not only the specific consequences of that modification style but the social and cultural context of the individual.

Figure 4.1: Illustration of Annularly Modified Cranium (Images after Anton, 1989; Blom, 2005)

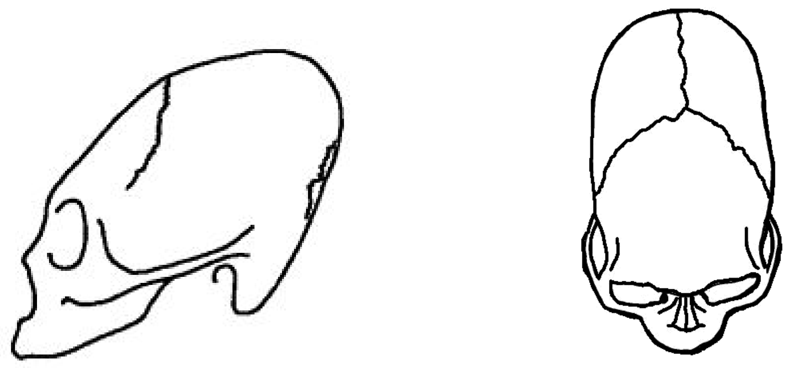

Figure 4.2: Illustration of Fronto-Occipitally Modified Cranium (Images after Anton, 1989; Blom, 2005)

Being mindful of the Osteological Paradox, there was an expectation among these data for a difference in lesion incidence between adults and juveniles. It is expected that juveniles would present with higher incidences of some of the conditions (e.g. porotic hyperostosis, bone necrosis, etc.) as compared to the adults as the juveniles died early in life, possibly prior to healing from the pathological effects of modification based on *selective mortality within a population*. As cranial modification is a practice that begins shortly after birth, it is suspected that most of the ACM-related pathological lesions would be more present and obvious in juveniles, particularly the very young juveniles, versus adults who survived and had sufficient time to heal any pathological lesions. This assumption is sample specific and due to the nature of the materials analyzed, complete crania. Young infants and juveniles who did not have partially fused crania were excluded from this study since they were unavailable for study at the time of data collection. If they had been included, it is expected that the lesion rates present in infants and young juveniles would be similar to those of the adult survivors as per the example provided by the *hidden heterogeneity in risks*.

Pooled modified and unmodified cranial data were also analyzed for the purposes of determining the proportions at age of death of modified and unmodified individuals (Table 4.3, Expectation 3). It was hypothesized that if a higher proportion of deceased modified individuals should exist in comparison to deceased unmodified individuals it would indicate that ACM increased mortality amongst modified individuals. The Osteological Paradox cautions that survivors may not exhibit lesions related to assaults to health, and therefore the accuracy of determining the risk to a population cannot be accurately assessed. This concern is, however, not particularly valid in this line of investigation as ACM is permanent and individuals cannot unmodify themselves. Therefore, the differences in incidences of deceased modified and unmodified individuals are real and can be quantified.

Table 4.3: Expectations

Expectation 1	A) Modified individuals will exhibit more mechanical & mechanical pathological lesions.
Expectation 1	B) There may be a pattern among modification styles with one or more exhibiting more mechanical and mechanical pathological lesions than the remaining, indicating these styles were more hazardous.
Expectation 2	A) Annular and annular oblique and erect modification styles, and styles 2, 3, 4, 11, and 12 would exhibit primarily occipital bone necrotic lesions, as well as premature suture fusion, sutural keeling, and asymmetry based on the locations of the modification devices associated with each ACM style.
Expectation 2	B) Fronto-occipital and fronto-occipital erect, forward, and reverse modification styles, and styles 5, 6, 7, 8, 9, 10, 13, 14, 15 would exhibit occipital and frontal bone necrotic lesions, premature suture fusion, sutural keeling, and asymmetry based on the locations of the modification devices associated with each ACM style.
Expectation 3	A) There would be an increased number of deceased modified individuals, particularly juveniles, which would indicate ACM increased mortality.
Expectation 3	B) An increased number of deceased individuals with specific modification styles may indicate that these styles caused more detrimental effects than others, particularly increased mortality.

4.5 Results

Incidence data from adults and juveniles were analyzed separately and divided by presence of modification and modification type. The following results will be separated by adults only and juveniles only in order to determine if either data set, adults or juveniles only, demonstrated greater effects on ACM and therefore were affecting the overall result. The proportion of modified adults and juveniles will also be presented.

4.5.1 Adults Only

Only three lesions were found with statistically significant differences between pooled modified and unmodified crania, and these included two mechanical lesions, grooves and indentations, and one mechanical pathological lesion, parietal bone necrotic lesions when the data were tested with the G-tests and divided between modified (all forms combined) and unmodified data (Table 4.4). All three of these lesions were found primarily among modified individuals, which is an expected result. The row by column Chi-square test did not yield statistically significant results, which does not meet the expectations.

Table 4.4: Mechanical & Pathological Lesions (Adults Only)-Modified (All Forms Combined) and Unmodified Crania

Sample Size=406

Pathological Condition	Type of Lesion	Present in Modified Crania (n=206)	Present in Unmodified Crania (n=200)	G-Test P-value
Cribra Orbitalia	S	39	46	.378
Dental Enamel Hypoplasia	S	81	87	.516
Parietal Bone Necrotic Lesions	S	**85 (41%)**	**59 (30%)**	**.005**
Thin Bone	M	115	108	.517
Grooves	M	**107 (52%)**	**75 (38%)**	**.002**
Bumps	M	78	74	.634
Asymmetry	M	83	96	.177
Indentations	M	**75 (36%)**	**45 (23%)**	**.001**
Premature Suture Fusion	MP	119	111	.453
Sutural Keeling	MP	29	32	.768
Occipital Bone Necrotic Lesions	MP	156	154	.791
Frontal Bone Necrotic Lesions	MP	7	10	.45
Internal Bone Necrotic Lesions	MP	51	55	.711
Table Chi-Square P-Value: .1061				

S=Stress Indicator; M=Mechanical Lesion; MP=Mechanical Pathological Lesion

Significant traits indicated in bold.

Percents for each trait by modified and unmodified samples are calculated for significant traits.

Crania classified by the Level 1 cranial forms had five statistically significant lesions as indicated by the G-tests (Table 4.5). The adult only data demonstrated statistically significant differences in grooving, a mechanical lesion found primarily amongst individuals with annular modification; asymmetry, a mechanical lesion found primarily amongst individuals with fronto-occipital modification; indentation, a mechanical lesion found primarily amongst individuals with fronto-occipital modification; parietal bone necrotic lesions, a mechanical pathological lesion found primarily amongst individuals with annular modification; and dental enamel hypoplasia, a pathological lesion found primarily amongst individuals with fronto-occipital modification. It is important to note that asymmetry, parietal bone necrotic lesions, and dental enamel hypoplasia were found with the second highest prevalence among unmodified crania. As noted above, this increased incidence of asymmetry may be related to childrearing practices or be a natural effect, while the increased incidence of parietal bone necrotic lesions and dental enamel hypoplasia may be related to other pathological conditions, such as anemia or scurvy. The row by column Chi-square test for the table did yield statistically significant results, confirming the significantly different combinations of lesions among these cranial forms. This result suggests that the lumping of the annularly and fronto-occipitally modified crania into a single "modified" category masks important differences in lesion incidence between the two forms (see also Chapter 3).

Table 4.5: Mechanical & Pathological Lesions (Adults Only)-Level 1 Typology
Sample Size=406

Pathological Condition	Type of Lesion	Present in Annular Crania (n=112)	Present in Fronto-Occipital Crania (n=89)	Present in Unmodified Crania (n=200)	G-Test P-value
Cribra Orbitalia	S	20	19	46	.843
Dental Enamel Hypoplasia	S	**37 (33%)**	**44 (49%)**	**87 (44%)**	**.001**
Parietal Bone Necrotic Lesions	S	**60 (54%)**	**25 (28%)**	**59 (30%)**	**.000**
Thin Bone	M	62	53	108	.654
Grooves	M	**63 (56%)**	**44 (49%)**	**75 (38%)**	**.004**
Bumps	M	48	30	74	.382
Asymmetry	M	**32 (29%)**	**51 (57%)**	**96 (48%)**	**.000**
Indentations	M	**31 (28%)**	**44 (49%)**	**45 (23%)**	**.000**
Premature Suture Fusion	MP	69	50	111	.860
Sutural Keeling	MP	16	13	32	.811
Occipital Bone Necrotic Lesions	MP	93	63	154	.082
Frontal Bone Necrotic Lesions	MP	4	3	10	.749
Internal Bone Necrotic Lesions	MP	30	21	55	.528
Table Chi-Square P-value: **.0008**					

S=Stress Indicators; M=Mechanical Lesion; MP=Mechanical Pathological Lesion

Significant traits indicated in bold.

Percents for each trait by modified and unmodified samples are calculated for significant traits.

When the Level 2 typology was tested, the G-tests yielded 2 mechanical, 1 mechanical pathological, and 1 pathological lesion that demonstrated statistically significant differences (Table 4.6). The two mechanical lesions were asymmetry and indentations, both of which were most commonly found among fronto-occipital erect modified crania. Asymmetry was found to be quite common among unmodified crania as these had the second highest incidence of this lesion, which may be an effect of childrearing practices. The one significant mechanical pathological lesion was parietal necrotic bone lesions, found most commonly among annular oblique crania; while the only significant pathological lesion was dental enamel hypoplasia, which was found most commonly among fronto-occipital erect modified crania. The row by column Chi-square test failed to find significant associations between lesion and cranial form, which is counter to the expectations as this result suggests that these lesions taken together as a whole did not negatively affect health (see Table 4.3). These results are suspect, however, as there are several cells with counts less than 5.

Table 4.6: Mechanical & Pathological Conditions (Adults Only)-Level 2 Typology

Sample size n=406

Pathological Condition	Type of Lesion	Present in Annular Oblique Crania (n=58)	Present in Annular Erect Crania (n=50)	Present in Fronto-Occipital Erect Crania (n=67)	Present in Fronto-Occipital Forward Crania (n=14)	Present in Fronto-Occipital Reverse Crania (n=11)	Present in Unmod-ified Crania (n=200)	G-Test P-value
Cribra Orbitalia	S	13	7	13	3	3	46	.629
Dental Enamel Hypoplasia	S	**21 (36%)**	**16 (32%)**	**34 (51%)**	**2 (14%)**	**8 (73%)**	**87 (44%)**	**.010**
Parietal Bone Necrotic Lesions	S	**29 (50%)**	**31 (62%)**	**19 (28%)**	**5 (38%)**	**2 (18%)**	**59 (30%)**	**.000**
Thin Bone	M	34	29	31	6	7	108	.062
Grooves	M	34	29	31	6	7	75	.062
Bumps	M	26	22	21	5	4	74	.934
Asymmetry	M	**19 (33%)**	**13 (26%)**	**40 (60%)**	**6 (43%)**	**5 (45%)**	**96 (48%)**	**.001**
Indentations	M	**14 (24%)**	**17 (34%)**	**36 (54%)**	**5 (36%)**	**3 (27%)**	**45 (23%)**	**.001**
Premature Suture Fusion	MP	31	31	41	8	5	111	.721
Sutural Keeling	MP	8	8	12	0	1	32	.693
Occipital Bone Necrotic Lesions	MP	52	41	48	8	8	154	.083
Frontal Bone Necrotic Lesions	MP	0	4	2	0	1	10	.124
Internal Bone Necrotic Lesions	MP	16	14	19	0	2	55	.090
Table Chi-Square P-value: .1167								

S=Stress Indicator; M=Mechanical Lesion; MP=Mechanical Pathological Lesion

Significant traits indicated in bold.

Percents for each trait by modified and unmodified samples are calculated for significant traits.

The results of the G-test from the Level 3 typology indicated statistically significant differences among the cranial forms for grooving and indentations, both mechanical lesions, and dental enamel hypoplasia, a pathological lesion (Table 4.7). Styles 9 and 11 had the highest frequencies among the grooving lesions, styles 7 and 15 demonstrated the highest frequencies of indentation lesions, and styles 6 and 15 exhibited the most prevalence of dental enamel hypoplasia. The row by column Chi-square test for the table did not demonstrate statistically significant association between form and lesions, but due to the majority of the cells containing counts of less than 5, this result is suspect.

Table 4.7: Mechanical & Pathological Conditions (Adults Only)-Level 3 Typology Sample Size n=406

Condition	Sutural Keeling	Frontal Bone Necrotic Lesions	Internal Bone Necrotic Lesions
Type of Lesion	MP	MP	MP
Present in Style 1 Crania (n=200)	32	10	55
Present in Style 2 Crania (n=10)	1	0	2
Present in Style 3 Crania (n=13)	0	0	3
Present in Style 4 Crania (n=13)	3	0	3
Present in Style 5 Crania (n=5)	0	0	2
Present in Style 6 Crania (n=3)	1	0	0
Present in Style 7 Crania (n=3)	8	0	7
Present in Style 8 Crania (n=8)	5	0	7
Present in Style 9 Crania (n=13)	0	0	1
Present in Style 10 Crania (n=3)	0	1	2
Present in Style 11 Crania (n=6)	0	0	0
Present in Style 12 Crania (n=29)	5	3	7
Present in Style 13 Crania (n=22)	2	0	1
Present in Style 15 Crania (n=18)	1	0	6
G-Test P-Value	.387	.268	.550
	Chi-Square (P-Value): .9381		

Table 4.7 continued

Condition	Grooves	Bumps	Asymmetry	Indentations	Premature Suture Fusion	Occipital Bone Necrotic Lesions
Type of Lesion	M	M	M	M	MP	MP
Present in Style 1 Crania (n=200)	**75 (38%)**	74	96	**45 (23%)**	111	154
Present in Style 2 Crania (n=10)	**1 (10%)**	3	2	**2 (20%)**	3	8
Present in Style 3 Crania (n=13)	**7 (54%)**	6	4	**2 (15%)**	5	12
Present in Style 4 Crania (n=13)	**5 (38%)**	2	7	**5 (38%)**	8	10
Present in Style 5 Crania (n=5)	**3 (60%)**	1	2	**2 (40%)**	3	3
Present in Style 6 Crania (n=3)	**0**	1	0	**0**	0	2
Present in Style 7 Crania (n=3)	**10 (34%)**	12	12	**17 (59%)**	17	21
Present in Style 8 Crania (n=8)	**15 (44%)**	15	11	**10 (29%)**	25	26
Present in Style 9 Crania (n=13)	**10 (91%)**	4	5	**3 (23%)**	6	9
Present in Style 10 Crania (n=3)	**8 (62%)**	3	5	**4 (36%)**	4	6
Present in Style 11 Crania (n=6)	**4 (67%)**	3	1	**0**	3	5
Present in Style 12 Crania (n=29)	**17 (59%)**	6	14	**10 (34%)**	19	23
Present in Style 13 Crania (n=22)	**4 (18%)**	5	3	**4 (18%)**	5	7
Present in Style 15 Crania (n=18)	**8 (44%)**	8	12	**8 (44%)**	12	15
G-Test P-Value	**.006**	.644	.149	**.015**	.268	.548
			Chi-Square (P-Value): .9381			

Table 4.7 continued

Condition	Cribra Orbitalia	Dental Enamel Hypoplasia	Parietal Bone Necrotic Lesions	Thin Bone
Type of Lesion	S	S	S	M
Present in Style 1 Crania (n=200)	46	**87 (44%)**	59	108
Present in Style 2 Crania (n=10)	2	**5 (50%)**	3	5
Present in Style 3 Crania (n=13)	3	**5 (38%)**	8	8
Present in Style 4 Crania (n=13)	3	**7 (54%)**	5	7
Present in Style 5 Crania (n=5)	1	**2 (40%)**	2	2
Present in Style 6 Crania (n=3)	1	**2 (67%)**	0	1
Present in Style 7 Crania (n=3)	3	**9 (31%)**	9	12
Present in Style 8 Crania (n=8)	8	**4 (12%)**	14	19
Present in Style 9 Crania (n=13)	3	**5 (38%)**	4	5
Present in Style 10 Crania (n=3)	3	**7 (54%)**	4	7
Present in Style 11 Crania (n=6)	1	**3 (50%)**	2	3
Present in Style 12 Crania (n=29)	5	**11 (38%)**	12	19
Present in Style 13 Crania (n=22)	2	**7 (32%)**	3	7
Present in Style 15 Crania (n=18)	15	**10 (56%)**	5	13
G-Test P-Value	.978	**.004**	.407	.718

P=Pathological Lesion; M=Mechanical Lesion; MP=Mechanical Pathological Lesion

Significant traits indicated in bold.

Percents for each trait by modified and unmodified samples are calculated for significant traits.

In summary, with the adult-only sample the distribution of only one lesion was consistently statistically significant among all the cranial forms: dental enamel hypoplasia, a pathological lesion. Parietal bone necrotic lesions, a mechanical lesion, were found to be statistically significant among the Level 1 & 2 typologies. While the results of the Level 3 typologies are statistically suspect, they do demonstrate broadly similar results to the Level 1 and 2 typologies, and this gives additional weight to the findings of association between cranial form and trait, even when multiple cranial forms are analyzed. As well, while parietal bone necrotic lesions were found to be most prevalent among modified crania, they were found in a high prevalence among unmodified individuals in the Level 1 typology but not the remaining typologies. Their increased presence among unmodified individuals may be related to other pathological conditions (e.g. anemia or scurvy). Several mechanical lesions, grooving, indentations, asymmetry, were found to be statistically significant as well, but these were not distributed evenly among the typological designations of the crania. This, too, was probably due to the atomization of the data, which is demonstrated by the reduction in statistically significant results as the complexity of the typologies increases. Asymmetry was found in high prevalence among the unmodified crania of the Level 1 and 2 typologies but not the remaining typologies. This increased prevalence may be related to childrearing practices.

Table 4.8 sumarizes the statistically significant traits found in this section. The row by column Chi-square test, however, demonstrated only statistically significant results for the Level 1 typology but none of the remaining typologies. This result is likely due to the atomization of the sample into the many ACM categories of Level 2 and 3. Therefore for the remainder of this study, I will only use the pooled modified versus unmodified scheme and the Level 1 typology.

Table 4.8: Summary of Statistically Significant Traits as Determined by the G-Test (Adults Only)

Typology	Mechanical Pathological Lesions	Mechanical Lesions	Stress Indicators
Modified/ Unmodified	**NONE**	Grooves	Parietal Bone Necrotic Lesions
		Indentations	
Chi-Square Test: Not Statistically Significant			
Level 1	**NONE**	Grooves	Dental Enamel Hypoplasia
		Asymmetry	Parietal Bone Necrotic Lesions
		Indentation	
Chi-square Test: Statistically Significant			
Level 2	**NONE**	Asymmetry	Dental Enamel Hypoplasia
		Indentations	Parietal Bone Necrotic Lesions
Chi-square Test: Not Statistically Significant			
Level 3	**NONE**	Grooves	Dental Enamel Hypoplasia
		Indentations	
Chi-Square Test: Not Statistically Significant			

4.5.2 Juveniles Only

When the data were divided by all modified types combined and unmodified crania among the juvenile only data and tested with the G-tests, one pathological lesion and one mechanical pathological lesion were found at statistically significant levels (Table 4.9). These traits were cribra orbitalia and premature suture fusion, and both were found in higher frequencies among modified individuals. These results meet the expectations for these data. The row by column Chi-square test, however, did not meet the expectations as there were no statistically significant differences among these data as a whole.

Table 4.9: Mechanical & Pathological Lesions (Juveniles Only)-Modified and Unmodified Crania

Sample Size n=102

Pathological Condition	Type of Lesion	Present in Modified Crania (n=61)	Present in Unmodified Crania (n=41)	G-Test
Cribra Orbitalia	S	**30 (49%)**	**12 (29%)**	**.043**
Dental Enamel Hypoplasia	S	17	20	.150
Parietal Bone Necrotic Lesions	S	18	10	.568
Thin Bone	M	46	27	.296
Grooves	M	28	21	.598
Bumps	M	14	9	.906
Asymmetry	M	32	26	.272
Indentations	M	20	15	.692
Premature Suture Fusion	MP	**51 (83%)**	**27 (66%)**	**.040**
Sutural Keeling	MP	12	9	.781
Occipital Bone Necrotic Lesions	MP	47	32	.906
Frontal Bone Necrotic Lesions	MP	7	1	.073
Internal Bone Necrotic Lesions	MP	28	18	.842
Table Chi-Square P-value: .599				

S=Stress Indicator; M=Mechanical Lesion; MP=Mechanical Pathological Lesion

Significant traits indicated in bold.

Percents for each trait by modified and unmodified samples are calculated for significant traits.

Crania classified by the Level 1 cranial forms demonstrated a statistically significant difference in prevalence of premature suture fusion, a mechanical pathological lesion, but no statistically significant difference among the remaining lesions when tested by the G-test (Table 4.10). Premature suture fusion was found in higher frequencies among individuals with the fronto-occipital modification but was also common among unmodified crania. A closer examination of the data shows that premature suture fusion is more common among the modified crania than the unmodified crania but this does not adequately explain why unmodified crania would exhibit premature suture fusion at all. Several factors could be responsible, including genetic predisposition to craniosynostosis, pressures related to wearing hats or caps (see below for discussion), or some other unknown factor. Further study into this matter should be completed. In addition, the frontal bone necrotic lesions are close to statistical significance, and there is a large difference in incidence among the fronto-occipitally modified crania as compared to annularly modified and unmodified crania.

Table 4.10: Mechanical & Pathological Lesions (Juveniles Only)-Level 1 Typology Sample Size n= 102

Pathological Condition	Type of Lesion	Present in Annular Crania (n=23)	Present in Fronto-Occipital Crania (n=38)	Present in Unmodified Crania (n=41)	G-Test
Cribra Orbitalia	S	10	20	12	.102
Dental Enamel Hypoplasia	S	6	11	20	.518
Parietal Bone Necrotic Lesions	S	7	11	10	.843
Thin Bone	M	15	31	27	.211
Grooves	M	10	18	21	.833
Bumps	M	5	9	9	.978
Asymmetry	M	9	23	26	.146
Indentations	M	6	14	15	.631
Premature Suture Fusion	MP	**17 (74%)**	**34 (89%)**	**27 (66%)**	**.035**
Sutural Keeling	MP	5	7	9	.916
Occipital Bone Necrotic Lesions	MP	17	30	32	.897
Frontal Bone Necrotic Lesions	MP	1	6	1	.070
Internal Bone Necrotic Lesions	MP	13	15	18	.423
Table Chi-Square P-value: .918					

S=Stress Indicator; M=Mechanical Lesion; MP=Mechanical Pathological Lesion

Significant traits indicated in bold.

Percents for each trait by modified and unmodified samples are calculated for significant traits.

In summary, the statistically significant lesions among the juvenile data are very different from the adult only data sets (Table 4.11), which reflects the difference between the juvenile and adult data sets. These results suggest that survivors will present with lesions, whereas those who die prematurely (e.g. the juveniles) do not live long enough to present with these lesions. Overall, there were no statistically significant differences for any of the tables.

Table 4:11: Summary of Statistically Significant Traits as Determined by the G-Test (Juvenile Only Data)

Typology	Mechanical Pathological Lesions	Mechanical Lesions	Stress Indicators
Modified/ Unmodified	Premature Suture Fusion	**NONE**	Cribra Orbitalia
Chi-Square Test: Not Statistically Significant			
Level 1	Premature Suture Fusion	**NONE**	**NONE**
Chi-square Test: Not Statistically Significant			

4.5.3 Proportions of Modified Crania Amongst Adults and Juveniles

Previous reports described the proportion of modified versus unmodified adults in the Azapa Valley around 50% for each (Cassman, 2000; Sutter, 2005). The present study included data from the Camarones and Lluta Valleys, which had not previously been studied, and the results from this study also show a similar proportion of modification amongst adults from all three valleys combined. At least 49% of adults were modified and 51% were unmodified. The proportion of juveniles with modification was 58% of the juvenile crania demonstrating modification and 42% demonstrating no modification. This suggests that modified juveniles were more likely to die prematurely than unmodified juveniles and conversely that unmodified individuals were more likely to survive to adulthood. The majority of the modified juveniles exhibited fronto-occipital modification styles, which could suggest that fronto-occipital modification styles may have increased mortality among the individuals surveyed assuming no other factors were involved in their deaths.

4.6 Discussion

Table 4.12: Expectations and Results

		Adult Only Data	*Juvenile Only Data*
Expectation 1	A) Modified individuals will exhibit more mechanical & mechanical pathological lesions.	**SUPPORTED** (Mechanical Lesions)	**SUPPORTED** (Mechanical Pathological Lesions)
Expectation 1	B) There may be a pattern among modification styles with one or more exhibiting more mechanical and mechanical pathological lesions than the remaining, indicating these styles were more hazardous.	**SUPPORTED**	**SUPPORTED**
Expectation 2	A) Annular and annular oblique and erect modification styles, and styles 2, 3, 4, 11, and 12 would exhibit primarily occipital bone necrotic lesions, as well as premature suture fusion, sutural keeling, and asymmetry based on the locations of the modification devices associated with each ACM style..	**NOT SUPPORTED**	**NOT SUPPORTED**
Expectation 2	B) Fronto-occipital and fronto-occipital erect, forward, and reverse modification styles, and styles 5, 6, 7, 8, 9, 10, 13, 14, 15 would exhibit occipital and frontal bone necrotic lesions, premature suture fusion, sutural keeling, and asymmetry based on the locations of the modification devices associated with each ACM style..	**NOT SUPPORTED**	**NOT SUPPORTED**
Expectation 3	A) There would be an increased number of deceased modified individuals, particularly juveniles, which would indicate ACM increased mortality.	**NOT SUPPORTED**	**SUPPORTED**
Expectation 3	B) An increased number of deceased individuals with specific modification styles may indicate that these styles caused more detrimental effects than others, particularly increased mortality.	**NOT SUPPORTED**	**SUPPORTED**

In general, the results of the adult only and juvenile only data do support the hypothesis that ACM increases morbidity amongst modified individuals based on the Expectation 1 (Table 4.12). Each data set, however, demonstrates a different biological effect possibly induced by ACM, warranting further discussion. When statistically significant differences in lesion incidence between modified and unmodified crania/cranial styles is present, modified adults demonstrate higher frequencies of mechanical lesions, particularly grooves, indentations, and asymmetry, and pathological conditions, particularly parietal bone necrotic lesions and dental enamel hypoplasia, whereas modified juveniles demonstrate higher frequencies of one mechanical pathological lesion, premature suture fusion, one mechanical lesion, asymmetry, but two pathological conditions, cribra orbitalia and parietal bone necrotic lesions.

The differences in types of lesions present between adults and juveniles are very informative and demonstrate when the mechanical pathological and mechanical lesions appear to have the most effect on a modified individual. Among the adults, the majority of statistically significant lesions are mechanical lesions, which alone does not support the hypothesis that ACM increased mortality as mechanical lesions on their own may not greatly increase the likelihood of death-they may, however, contribute to other conditions (e.g. growth disruptions or greater susceptibility to injury in trauma) that could increase mortality. It is difficult, however, based on the general age status of these individuals, as cautioned in the Osteological Paradox, to discern the extent and the full effects of the mechanical pathological conditions that may have been and are noted to be present among these individuals. The incidence of premature suture fusion among modified and unmodified adults is high, but it is unclear the accuracy of the presence of this lesion without proper age estimations. At the time of data collection, post-cranial remains were unavailable for survey, meaning that specific age-at-death estimates could not be taken. Therefore, it is not possible at this time to know if the prematurely fused sutures are the products of aging or ACM. Furthermore, one cannot know the exact time when suture fusion began in adults given the nature of this sample (see *selective mortality of a population*). Keeling among the adult individuals was rather infrequent, and it would appear that craniosynostosis was not a serious problem among *these* individuals. It is assumed that the detrimental effects of craniosynostosis would be felt earlier in life, prior to adulthood, and individuals suffering from this condition would not reach adulthood.

As well, it is difficult to discern with accuracy the presence of bone necrotic lesions in adults. These lesions are usually indiscernible or present in minor, healed states as the mechanisms that cause porotic hyperostosis are most active during childhood (Ortner, 2003). While adults in this sample do demonstrate variable incidence of these lesions throughout the skull, most evidence demonstrates a healed, inactive state of the lesion. The timings of when these lesions were most active are therefore indiscernible, making these lesions difficult to evaluate in adults. Also, it is expected that individuals with the most detrimental effects from porotic hyperostotic lesions (and the corresponding root cause of the lesion) would perish earlier in life, further complicating the matter of evaluating this lesion in adults.

As noted in the Osteological Paradox, the adults in this sample are the survivors of the assaults to their health and may not be accurate measures of the effects of ACM, a conclusion supported by the results herein. The increased incidences of mechanical lesions among the modified individuals does seem to support the overall hypothesis that ACM will increase morbidity as these individuals do demonstrate some ACM-related consequences on their bones. The presence of these lesions among the adult survivors, however, also supports the idea that their presence alone will not increase mortality. They instead represent possible lasting effects of ACM-related pathological consequences.

Further analysis of the adult data does demonstrate the presence of a high incidence of mechanical lesions among unmodified individuals, which is unexpected since these individuals were not subjected to ACM. Unmodified individuals show the second highest frequencies of asymmetry as compared to modified cranial forms. This result may indicate that asymmetry was a naturally occurring trait within these populations, which if true, would negate the classification of this lesion as ACM related. Reanalysis of this lesion among unmodified crania demonstrates that asymmetry in unmodified individuals is mild and not as pronounced as among modified crania. Asymmetry among unmodified crania could still indicate that it was a naturally occurring trait that was further pronounced by ACM devices or it could have been a result of improper sleeping postures during infancy. It is unknown what preferences ancient groups may have had in regards to sleeping apparatuses or postures among infants, although it is known that some infants were placed in cradles (Allison *et al*., 1981b; Standen, pers comm., 2009), but little else is known about the sleeping patterns of ancient groups. Alternatively, asymmetry among unmodified crania could be a nonspecific indicator related to environmental stress (Buikstra and Cook, 1980). It is known from previous studies the northern Chilean groups under study were environmentally stressed from disease (cf. Allison *et al.,* 1982; Arriaza *et al*., 1995; Aufderheide *et al*., 2008; Guhl *et al*., 1999;

Standen and Arriaza, 200a), poor nutrition (cf. Allison *et al.*, 1982; Allison, 1984; Aufderheide *et al.*, 1993), and environmental contaminants (cf. Arriaza, 2005), and the asymmetry noted within these populations could be an indicator of general stress. Further analysis is necessary to determine if there is a relationship between asymmetry in unmodified individuals and increased biological stress.

Unmodified individuals also demonstrate fairly high incidence of grooves (38%) and indentations (23%). The presence of grooves among unmodified individuals could be the result of improper sleeping posture dependent on the type of sleeping apparatus used (e.g. sleeping with head partially within the cradle limits), or it could be due to the tradition of wearing hats. There exist many ethnohistoric accounts regarding the importance of ancient Andean groups wearing hats in order to display their social identity (Cieza de Leon, 1984 [1553]; de la Vega, 1966 [1609]; de las Casas, 1892 [1561]), and archaeological evidence from ancient northern Chilean groups demonstrates that these groups were quite partial to wearing hats (Berenguer, 2006). These hats are believed to have been fashioned in a manner to ensure their optimal placement on the head, suggesting that some sort of pressure on the cranium may have been produced. There is evidence in the form of a mummified infant wearing a tight fitting cap currently housed in the Physical Anthropology Laboratory at the museum, suggestive of this practice beginning quite early in life when the skull is still malleable and plastic. The overall effects of wearing a hat would not have been as extreme as those of ACM but still may have been enough to cause grooves on the skull.

Both modified and unmodified adults demonstrated incidence of parietal bone necrotic lesions and dental enamel hypoplasia, each of which were found in higher frequencies among modified individuals. These are both pathological conditions that are not believed to be related to ACM. Parietal bone necrotic lesions are believed to be characteristic of disease processes, particularly anemia, scurvy, rickets, etc., and dental enamel hypoplasia is believed to represent stress on the body during dental development (Ortner, 2003). It is well known from previous studies that northern Chilean groups were nutritionally deficient due to parasitic infestations and a heavy reliance on one food staple (e.g.

seafood among coastal valley groups and maize among inland groups) (Allison *et al.*, 1982; Allison, 1984; Aufderheide *et al.*, 1993), which may have caused these individuals to develop anemia or rickets and be the cause of the porotic hyperostosis and dental enamel hypoplasia. Previous studies of other Andean groups demonstrate that coastal Peruvian groups demonstrate higher frequencies of porotic hyperostotic lesions that are attributed to anemia (c.f. Blom *et al*., 2005; Pechenkina and Delgado, 2006; Ubelaker, 1992), and the conditions suffered by these groups and the northern Chilean groups are similar enough to warrant a connection.

Unfortunately, due to the nature of the materials available at the time of data collection, the post-cranial remains could not be analyzed in order to make a definitive diagnosis either way-to determine or rule out potential causal factors of these lesions. As well, analysis of dental stress indicators related to these other conditions could not be accurately assessed due to the scarcity of teeth available for all individuals due to natural or postmortem loss. The presence of porotic hyperostotic lesions among all areas of the skull and high frequencies of dental enamel hypoplasias among modified and unmodified individuals seems to suggest that ACM was not the causal factor. As well, specific knowledge of the origin (i.e. highland or lowland) of individuals in this study could aid in narrowing the possible other causal effects of these lesions.

There is, however, a statistically significant increased incidence of porotic hyperostotic lesions and dental enamel hypoplasia among modified individuals. The presence of more modified individuals with porotic hyperostotic lesions does seem to suggest that ACM contributed to an increase in lesion presence. This increase in lesions may be attributable to the pressures related to the device or cultural treatment (e.g. nutrient poor diet, preference for raw or undercooked seafood, etc.). While there is no known relationship between ACM and dental enamel hypoplasia, the presence of more modified individuals with this lesion does seem to suggest that these individuals were more biologically stressed than unmodified individuals. The types of stress incurred by modified versus unmodified individuals are unknown but may be related to nutritional stress caused by differential cultural treatment, biological stress from disease or the processes related to

ACM, or psychological stress from pain associated with ACM processes (e.g. tightening the bindings). Further analysis is necessary to determine the causes of the dental enamel hyploplasias noted among modified and unmodified individuals in order to determine if these lesions are indicative of biological stress from ACM. At this time, it appears that this evidence demonstrates a slight relationship with ACM but none that was severe enough to induce death as these individuals survived to adulthood.

There are fewer significant lesions present among the juvenile only data, but the lesions include one mechanical pathological lesion, premature suture fusion, one mechanical lesion, asymmetry, and two pathological conditions, cribra orbitalia and parietal bone necrosis. The premature suture fusion lesions are consistently present in higher frequencies among modified juveniles, suggestive of them being a consequence of ACM, but unmodified juveniles also demonstrate a high frequency (over 50%) of premature suture fusion. This high frequency among unmodified juveniles could be indicative of premature suture fusion being a naturally occurring/hereditary trait in these populations, meaning that all individuals, regardless of modification presence, would be predisposed to having premature suture fusion and eventually craniosynostosis. The increased frequency of this lesion among modified individuals, however, demonstrates that ACM may have advanced the progress of this lesion, leaving modified individuals more vulnerable to the full effects of craniosynostosis earlier in life. Ancient Maya populations with a tendency toward craniosynostosis and who practiced ACM demonstrate an increased incidence of this lesion among modified individuals, which is attributed to the pressures induced by ACM (White, 1996). Overall, this result demonstrates that while premature suture fusion may have been a naturally occurring trait within these populations, ACM was possibly amplifying the effect and leaving juveniles, in particular, more vulnerable to the consequences.

The presence of cribra orbitalia and parietal bone necrotic lesions, both pathological conditions, demonstrate that the juveniles, particularly those with ACM, were undergoing some sort of biological stress. As cribra orbitalia is also a type of porotic hyperostosis, it could be that both lesions are demonstrating similar stresses on the body-derived from nutritional or pathological stress, which is reasonable given the previous evidence of nutritional and pathological stresses these groups were exposed to (Allison *et al.*, 1982; Allison, 1984; Arriaza, 1995; Kelley and Lytle, 1995; Kothari *et al.*, 2009; Rothhammer *et al*., 1985; Standen and Arriaza, 2000a). Both lesions are, however, found in higher frequencies among modified individuals. Careful analysis of the morphological changes induced by ACM demonstrates that the orbital metrics are changed in modified individuals (Boston, Chapter 3). Cribra orbitalia lesions among modified individuals could be indicative of not only nutritional or pathological stress but of growth remodeling related to the changing form of the orbit. As well, all modified individuals demonstrate higher frequencies of porotic hyperostosis among all of the regions of the skull, which could indicate that ACM was, in part, causing this lesion. This explanation does not negate the presence of nutritional or pathological stresses on the body, but instead suggests that modified juveniles may have undergone additional stresses related to ACM- be they from the physical process of manipulating the cranium or cultural treatment related to the social motivation tied to modification (e.g. different diet, lack of hygiene, etc.). Holliday (1993) attributed occipital bone necrotic lesions among modified juveniles to the improper hygienic control of the back of the skull related to cradleboarding, while other scholars noted that modified crania were washed when devices were removed, which varied from daily to monthly (Blackwood and Danby, 1955; Boas, 1921; Dingwall, 1931). It is unclear if unmodified individuals received a different diet or adhered to a stricter hygiene routine compared to modified individuals.

Overall, the sampled juveniles demonstrate far fewer lesions than the adults and than what is expected if ACM were increasing morbidity to the point of increasing mortality, too. The lack of lesions in general among these juveniles is not unexpected given the cautionary notes of the Osteological Paradox. A specific amount of time is needed for osseous lesions to occur, and a sufficient amount of time may not have passed for all the lesions to present on these juveniles' bones. Therefore, it may be that that it is best to test this hypothesis when soft tissues are present, as was done in the previous studies (Guillen *et al.*, 2009; Mendoca de Souza *et al.*, 2008).

Based on Expectation 2, specific responses of bone related to ACM were expected to occur for particular modification styles. This, however, does not seem to be supported by the results of this investigation. Annular and fronto-occipital modifications and variant styles were expected to demonstrate increased incidences of specific mechanical lesions such as occipital bone necrotic lesions, premature suture fusion, sutural keeling, and asymmetry. Of these four lesions, asymmetry was the lesion that was most commonly present at statistically significant levels, particularly among fronto-occipital and variant styles, but it was not the most common lesion, as grooves and indentations were. Statistically significant differences for asymmetry were less common and only present among the Level 1 and 2 typologies of the adults only data. Indentations were equally prevalent among most cranial forms in this data set, and grooves were more common among fronto-occipital erect styles. Analyses not presented here shows that the juvenile only data do not demonstrate statistically significant differences among these two lesions among any of the surveyed typologies. While the specific details of Expectation 2 were not met, the different proportions of grooves and indentations among specific cranial forms seems to, in part, support Expectation 2.

As per Expectation 3, if the primary hypothesis, which states that ACM increased mortality, is to be supported, there should be a high proportion of deceased modified individuals as compared to unmodified individuals. This expectation is not supported in the adult only data as the proportion noted among the adults demonstrate almost equal proportions of modified and unmodified individuals. This result is not unexpected given that the *hidden heterogeneity of risks* among these individuals cannot be assessed. These individuals were the survivors to any possible ACM-related risks and consequences, and as previously mentioned, the overall effects of ACM cannot be evaluated as evidenced by the lack of mechanical pathological conditions present within this sample. It is unclear, however, if ACM caused those individuals who survived to be modified adults to die sooner as a result of the increased childhood stresses than their unmodified adult counterparts. The specific age ranges of the adults surveyed in this investigation are unknown as postcranial remains were unavailable at the time of data collection. At this time, this idea cannot be fully examined, but it may be worthwhile to explore it further at a later time.

The juvenile only data, however, do support this expectation as 58% of the juveniles surveyed in this investigation demonstrated cranial modification. While not an overwhelmingly large proportion of the data, this proportion does suggest that ACM did increase the likelihood of premature death at some level as a larger proportion of modified children were dying before they could reach adulthood as compared to their unmodified counterparts. This result is supported by the presence of more mechanical pathological lesions among modified juveniles.

A closer examination of the data shows that there is no clear majority ACM style among the juveniles. Approximately 51% of young juveniles (ages 2-5; n=37) exhibited fronto-occipital and variant styles, while 49% of these juveniles exhibited annular and variant styles. This result does not demonstrate that any particular ACM style was associated with more negative consequences than another ACM style. Based on these results, it appears that within this sample, both annular and fronto-occipital modification styles were equally likely to increase morbidity and mortality despite proportional differences in lesion presence among these various ACM styles.

A previous study, however, demonstrated no differences in health between a sample of coastal and inland juveniles (Boston, 2009). Also, a study by Blom *et al*. (2005) noted little difference in "health" based on porotic hyperostotic lesions on the cranium between fishers and agriculturalists. This suggests that differences in diet may have had little effect on overall health of these individuals.

4.7 Conclusion

ACM has been practiced for thousands of years and continues on in rare instances today. People felt compelled to practice cranial modification for myriad reasons as dictated by cultural or religious norms despite the negative effects on the body and health of the individual. Previous studies have concluded that these effects were minimal and did not appear to be lethal, although they could carry some risks to overall health (Gerszten, 1993; Holliday, 1993; MacLellan, 2006). The purpose of this study was to further explore these risks and determine if the presence of a combination of these risks could cause an overall increase in morbidity and mortality amongst a relatively contained population. Mechanical pathological lesions associated with ACM, including bone necrosis of the occipital and frontal bones as well as endocranium and premature suture fusion and mechanical lesions associated with ACM, including sutural keeling, thin bone, grooving, bumps, asymmetry, and indentations, were examined, along with stress indicators, such as cribra orbitalia, bone necrosis of the parietal bones, and dental enamel hypoplasia, that could indicate the presence of other disease processes. Overall, some of the results of this study support the hypothesis that ACM can increase morbidity *and* mortality (cf. Guillen *et al.*, 2009; Mendoca de Souza *et al.*, 1998), demonstrating the importance of the cultural norms and values associated with ACM despite the real and potentially lethal consequences tied to it. Modified individuals presented with increased proportions of mechanical pathological and mechanical lesions as well as stress indicators when compared to unmodified individuals, although unmodified individuals also presented with high proportions of some of these lesions. These results ultimately support the expectations of this study, but also highlight areas of further investigation regarding how other customs, such as child rearing, may have affected these data. As well, the proportions of deceased modified juveniles were higher than unmodified, further supporting the hypothesis that ACM can increase mortality. This proportion evened out by adulthood, suggesting that the effects of ACM on morbidity and mortality may be minimal by the time an individual reached adulthood, but further study is necessary in order to determine if the negative effects suffered in childhood affected adult mortality.

The second hypothesis proposed that one or more cranial forms would present more of a hazard to health than the others. The results herein demonstrate that no one ACM style affected health more so than another, which does not support this hypothesis. There was evidence to suggest that all ACM styles surveyed exhibited ACM-related lesions, although at different proportions. This result demonstrates that ACM in general will increase morbidity and mortality, and that the practice of ACM, regardless of methods and final cranial form, was of such importance that it continued despite the risk to health.

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Chapter 5

5 Identity Crisis: A Reanalysis of the Social Motivations of ACM among Northern Chilean Populations

Artificial cranial modification (ACM) was practiced in many different parts of the world, throughout history (Dingwall, 1931), but this practice was especially prevalent in South America (Virchow, 1892). ACM results from the physical manipulation of an infant's skull shortly after birth, prior to the complete ossification of the cranial bones, using a variety of containing devices including boards, rocks, textiles, rolls of cotton or wool, and cradles (Cieza de Leon, 1984 [1553]; de la Vega, 1966 [1609]; Diez de San Miguel, 1964 [1567]; Dingwall, 1931; Torquemada, 1995 [1557-1664]; Weiss, 1961). Ethnographic evidence indicates that the binding could either be permanent or installed for specific lengths of times based on days or weeks, and the desired final cranial shape could be achieved over a period ranging between 6 months and 5 years, although sometimes go as long as 16 years among certain European groups (Boas, 1921; Cieza de Leon, 1984 [1553]; de la Vega, 1966 [1609]; Dingwall, 1931; Morton, 1839). The result was a child with a specific cranial form readily identifiable by others (Blom, 2005a & 2005b; Blom *et al.*, 1998; Torres-Rouff, 2002, 2003, 2009).

The ethnohistoric record for the Andean region of South America suggests the existence of a number of cultural motivations for practicing ACM, including ethnicity, social status, social class, sex, prevention of attack from evil spirits, improvement of health and work ethic, and an appearance of ferocity in battle (cf. Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; Dingwall, 1931; Morton, 1839; Torquemada, 1995 [1557-1664]; Stewart, 1943; Weiss, 1961). Despite these various motivations, scholars have traditionally agreed that ACM was primarily used as a marker of ethnicity, whereby members of different ethnic groups practiced distinctive head shapes (Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; de la Vega, 1966 [1609]). Over the years scholars have provided evidence to support this assertion (Dingwall, 1931; Hrdlička, 1912; Stewart, 1943; von Tschudi, 1846; Weiss, 1961) and several recent bioarchaeological studies have also given support to this hypothesis (Blom, 1999 & 2005b; Hoshower *et al.*, 1995; Torres-Rouff, 2002, 2003, 2009). They identify the existence of a geographic clustering of ACM styles in the Andes, especially between highland and coastal groups, which was attributed to the physical expression of distinct ethnic identities.

Ethnicity, in this context, is defined as the classification of groups of people sharing similarities in biological origin, culture, language, ideology, history, and citizenship (Banks, 1996; Eriksen, 1993; Geertz, 1963; Hutchinson and Smith, 1996; Jones, 1997 & 2008; Lucy, 2005; Weber, 1978). Scholars do recognize that not all of these characteristics may be represented, and the lack of one or more of these criteria does not negate the existence of an ethnic group (Bromley, 1974; Eriksen, 1993; Williams, 2005). Through day to day interactions, the ethnic groups maintain the social boundaries of their ethnicity by reinforcing these markers of identity within the group and, by default, displaying them to outsiders (Barth, 1969). Scholars use visual and physical representations thought to reflect ethnicity, including differences in styles of ceramics (Arnold, 1998; Dever, 1995; Esse, 1992; Jamieson, 2001; Janusek, 2005; Julien, 1993), architecture (Aldenderfer and Stanish, 1993; Bawden, 1993 & 2005; Conrad, 1993; Stanish, 1989 & 2005), lithics (Sherrat, 1990; Wiessner, 1983), textiles (Cassman, 1997 & 2005; Keith, 1998; Rodman, 1992; Rodman and Lopez, 2005), body ornamentations and modifications (Arriaza, 1988; Blom *et al.*, 1998; Blom, 2005; Hoshower *et al.*, 1995; Sutter, 2005; Tiesler-Blos, 2010; Torres-Rouff, 2002, 2003, 2009), and language (Evison, 2001; Lindstrom, 2001; Mac Eachern, 2001), to identify ethnic groups in the past. Within ancient Andean contexts, ceramics, architecture, textiles, and body modifications are believed to represent ethnic identity based on ethnohistorical and bioarchaeological evidence (Aldenderfer and Stanish, 1993; Arriaza, 1988; Bawden, 1993 & 2005; Blom *et al.*, 1998; Blom, 2005; Cassman, 1997 & 2005; Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; de la Vega, 1966 [1609]; Janusek, 2005; Hoshower *et al.*, 1995; Rodman, 1992; Rodman and Lopez, 2005; Stanish, 1989 & 2005; Torres-Rouff, 2002, 2003, 2009)

These assessments of ACM as a marker of ethnic identity have recently been called into question, however, based on dissenting ethnohistorical documentation (de las Casas, 1892 [1561]; Torquemada, 1995 [1557-1664]) and bioarchaeological and archaeological research (Boadas-Rivas, 1995; Cassman, 1997 & 2000; Doutriaux, 2004; Sutter, 2005). These studies suggest that ACM was used as a marker of social status among pre-Columbian societies of the Andes, a conclusions based on several lines of evidence, including the correlations among ACM styles and grave goods (Boadas-Rivas, 1995; Cassman, 1997 & 2000; Doutriaux, 2004), a reassessment of the geographical distributions of ACM styles (Cassman, 1997 & 2000; Sutter, 2005), and the use of epigenetic traits (Sutter, 2005).

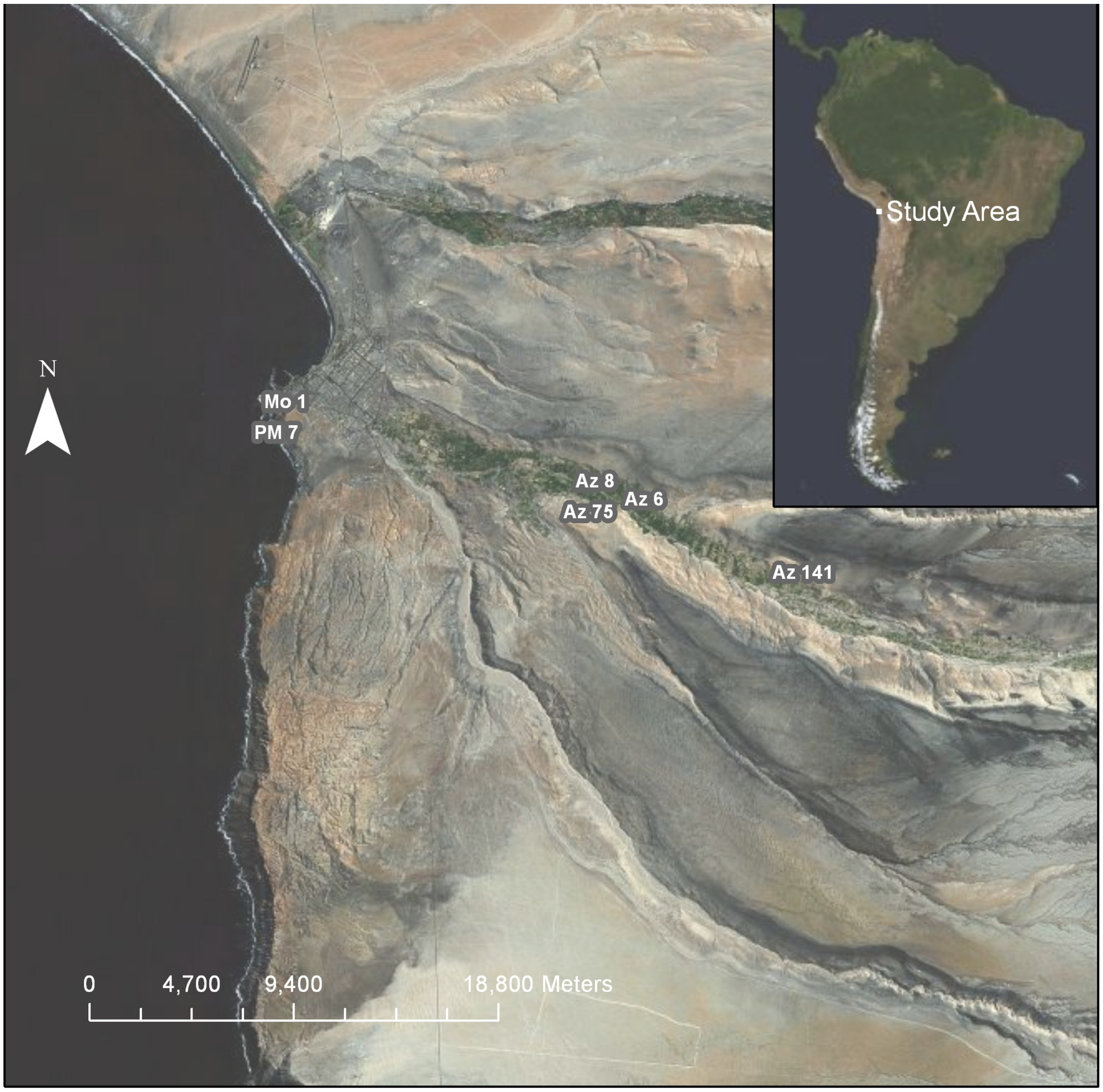
Social status is a form of identity based on the consumption and control of both essential and nonessential resources within a group. It is divided into two types: ascribed and achieved (Ames, 2008; Babic, 2005; Wason, 2004). Ascribed status is inherited at birth, whereas achieved status is attained in life through deliberate effort by the individual (Ames, 2008). Social status is often identified through various forms of material culture (Henrich and Gil-White, 2001), but is also identifiable through body modifications (Brain, 1979; Dingwall, 1931). A variety of material goods have been used to identify status, such as items made from rare materials, that are finely crafted, or nonutilitarian in nature (Ames, 2008; Wason, 2004). As well, long distance trade items are identified as high status based on the amount of time and energy necessary to acquire those goods. Goods that are easily attainable, utilitarian in nature, or created from local, easily acquired materials that are designated for every day use are generally considered to be lower status or common items (that may be associated with specific ascribed status) (Ames, 2008; Wason, 2004). When young children are accompanied by high status goods, the status is interpreted as being ascribed rather than achieved. It is important to note that some body modifications (e.g. ACM) cannot be a marker of achieved status because they are imposed on an individual at birth before they could achieve any wealth or prestige associated with achieved status, while other body modifications (e.g. scarification) can be associated with achieved status.

Although evidence seems to support both of these hypotheses (ACM as marker of ethnicity and ACM as marker of social status), no systematic study has yet tested these competing hypotheses using a single dataset. This paper aims to test these two hypotheses using a single dataset collected by the author during 5 month-long fieldwork in northern Chile. This study is based on a dataset which consists of 435 individuals from three northern Chilean valleys. These valley groups are demarcated by their settlement of either the coastlines or inland valley floors, which are herein referred to as coastal valley and inland valley respectively. No highland groups, those residing in the Andes, are referenced in this study. The collections are currently housed at the Museo Arqueologico de San Miguel de Azapa near Arica, Chile. These samples were derived from Formative to Late Period collections, spanning a three thousand year period with varying degrees of social complexity.

5.1 Background

The study area of northern Chile is located within the Atacama Desert, a region considered to be the most arid in the world (Figure 5.1) (Arriaza *et al.*, 2008). This region is extremely inhospitable, providing limited resources for successful human occupation. Archaeological sites are concentrated along the marine coasts and within the fertile river valleys (Arriaza, 1995a; Gallardo, 2009). Archaeological evidence demonstrates that the region has been occupied for several millennia despite these harsh conditions (Aufderheide, 2003).

Figure 5.1: Map of Northern Chile (Azapa Valley) (after ArcMap)



The first evidence for human occupation in the region is found prior to 8000 B.C. in the pre-Archaic Period. The archaeological evidence supports the existence of several permanent settlements in the river valleys and seasonal occupations in the Andean highlands, as well as trade between and among groups residing in these areas (Standen and Nuñez, 1984). Both valley and highland groups had their own distinctive material culture and settlement patterns.

The Archaic Period dates from 8000 to 1500 B.C. and is characterized by two separate and distinctive cultures: the Chinchorro and Quiani (Arriaza, 1995a & b; Arriaza *et al.*, 2008; Guillen, 1992). Both cultures settled and occupied the northern Chilean valleys (Santoro, 1993), although in separate areas herein referred to as the coastal valley, designating groups inhabiting the coast line, and inland valley, designating groups inhabiting the valley floor. The Chinchorro culture was a coastal-fishing tradition that remained largely unchanged for approximately 5000 years (Allison *et al.*, 1984; Arriaza, 1995a & b; Arriaza *et al.*, 1986 & 2008; Guillen, 1992; Standen, 2003). The Chinchorro are best known for their anthropogenic mummification techniques (Arriaza, 1995b; Guillen, 1992), which are believed to possibly have been practiced with specific members of the society as a marker of status or rank (Standen, 1997). The Chinchorro settled the valley coastlines in semi-sedentary villages (Arriaza *et al.*, 2008; Aufderheide *et al.*, 1993; Guillen, 1992; Muñoz, 2004). They primarily consumed and exploited marine resources based on isotopic, pathological, coprolite, and material culture evidence (Arriaza *et al.*, 2008; Aufderheide *et al.*, 1993; Focacci and Chacon, 1989; Guillen, 1997; Muñoz, 2004; Reinhard and Urban, 2003; Santoro *et al.*, 2003; Schiappacasse & Niemeyer, 1984; Skottsberg, 1924, cited in Guillen, 1992; Standen, 1997; Uhle, 1919 & 1922), but they also exploited inland resources at significantly decreased proportions (Arriaza *et al.*, 2001; Aufderheide *et al.*, 1993; Guillen, 1997; Nuñez, 1983; Santoro *et al.*, 2003). The Chinchorro did not practice ACM.

Scholars believe the Quiani were either a group of highland migrants or a displaced group of coastal immigrants who incorporated highland cultural elements (Dauelsberg, 1974). This culture is associated with crudely produced pottery, horticultural practices, cotton and camelid wool textiles, turbans and hair braiding, new mortuary practices, and ACM practices (Arriaza, 1995a; Bird, 1943; Dauelsberg, 1974; Muñoz , 2004). The literature does not describe their ACM practices, but Dingwall (1931) and Morton (1839) both briefly describe ACM among northern Chilean groups. Neither Dingwall (1931) or Morton (1839) describe the cultural affiliations or periods for the samples they used in their analyses, but it is assumed that they worked with materials excavated from the Archaic Period given the collections available at time of publication of those studies.

Dingwall (1931) states that annular and fronto-occipital ACM styles were common among groups residing in the Atacama Desert, but Morton (1839) pinpoints that annular ACM styles were most prevalent among groups residing in and around the modern day coastal city of Arica, Chile. Based on this evidence, there are at least two ethnic groups present during this period and possible evidence of social status or ranking in at least one society.

The Formative Period, dated from 1500 B.C. to 500 A.D., is characterized by the interaction between highland and coastal groups (Berenguer and Dauelsberg, 1989; Muñoz, 1987; Moraga *et al.*, 2005; Rivera, 1977; Rothhammer *et al.*, 2002; Santoro, 1980a, b, & c; Santoro and Ulloa, 1985; Varela and Cocilovo, 2002). Coastal and inland valley groups were also deeply involved in trade and possible intermarriage despite both groups appearing to be ethnically and culturally distinct (Focacci, 1974; Focacci and Chacon, 1989; Llagostera, 2010; Muñoz, 1989; Santoro, 1980a, b, & c). The coastal and inland valley groups are distinguished by their subsistence strategies, pottery styles, and mortuary customs (Dauelsberg, 1985; Focacci, 1974; Focacci and Chacon, 1989; Muñoz, 1981, 1987, and 1989; Rivera, 2008; Santoro 1980a & b).

Coastal valley groups specialized in marine subsistence strategies (Rivera, 2008). They practiced two distinct ceramic traditions known as Faldas del Morro and El Laucho, which were practiced in the first half and second half of the period respectively (Dauelsberg, 1985; Focacci, 1974; Focacci and Chacon, 1989). Coastal valley groups also practiced common mortuary rituals with deceased individuals buried with few grave goods, which included harpoons, chopes, reed baskets, vegetable fiber broaches, drug tool kits (Focacci, 1974; Focacci and Chacon, 1989). These groups also practiced ACM at increased proportions as compared to the previous period. Inland valley groups occupied the interior valleys and practiced a mixed agro-pastoralism and maritime subsistence strategy (Muñoz, 1989; Rivera, 2008; Santoro 1980a, b, and c). ACM was widely practiced by inland groups, who had several different modification styles (Allison *et al*., 1981). Inland groups practiced two different pottery styles: the Azapa and Alto Ramirez traditions, also practiced in the first and second halves of this period (Santoro, 1980a & b). The burial customs practiced by the inland groups varied between burials with the bodies wrapped in reed mats and most often interred with no grave goods (Muñoz, 1981, 1987, & 1989; Santoro 1980a, b, and c) and tumulo, or burial mound, burials (Muñoz 1981, 1987, 1989). There is mortuary and material evidence attributed to support of ethnic conflict between coastal valley and inland valley groups during the later part of this period (Standen *et al.*, 2010). Taken together, the cultural evidence (e.g. material culture, subsistence strategies, and mortuary traditions) demonstrates that at least two but possibly four distinctive ethnic groups existed at the regional level, but there has been little study concerning rank or status differentiations among these groups.

The Middle Horizon (AD 500 to 1100) is described as a period of either colonization by or strong influence from the Tiwanaku polity (Kolata, 1993). Some scholars believe that Tiwanaku elites colonized and controlled the region and exploited it (Berenguer, 1978; Focacci, 1969; Kolata, 1993; Lumbreras, 1972; Moraga *et al.*, 2005; Mujica *et al.*, 1983; Rivera, 1977, 1991, 2008; Rothhammer *et al.*, 2002; Varela and Cocilovo, 2002), but others feel that this period was marked by extensive trade with this distant city (Sutter, 1997, 2000, 2005, 2006; Sutter and Mertz, 2004). Scholars identified a concentration of inland valley settlements during this period, and coastal valley settlements appear to have been minimally used, if not completely abandoned (Berenguer and Dauelsberg, 1989; Focacci 1981). There was an intensification of agricultural subsistence strategies, as well as the introduction of new metallurgical, ceramic, wood and leather working, and textile manufacture techniques and styles (Goldstein, 1996 & 2005; Rivera, 2008). New ACM and hair styles were also introduced (Allison *et al.*, 1981; Arriaza *et al.*, 1986). Mortuary traditions were characterized by flexed, bundle burials wrapped in wool textiles interred in either pit or stone-lined tombs, which is consistent with Tiwanaku mortuary traditions (Stanish, 2003), with a variety of grave goods of highland and valley origins (Browman, 1997; Goldstein, 1996 & 2005; Muñoz, 1989). During the Middle Horizon, there is believed to have been at least two ethnic groups (the Tiwanaku and the local inland valley inhabitants) who would have been socially stratified as prescribed by the dynamics of conquest and control based on the cultural evidence.

The Regional Development Period dates from AD 1100 to 1476 and is characterized by the reduction in Tiwanaku's influence and/or control over the region and is exemplified by the emergence of new, local cultures and traditions, considered to represent different ethnic groups (Rostworowski, 1986), that occupied both the coastal valley and inland valley (Rivera, 2008; Schiappacasse *et al*., 1989; Sutter, 1997). This period was also a time of unrest based on the presence of defensive architecture (Rivera, 2008), and Llagostera (2010) suggests that raids from the highlands were frequent. Coastal and inland valley groups carried out subsistence strategies and trading practices reminiscent of those in the Formative Period (Muñoz , 2004). Coastal valley groups fished and exploited marine resources, while inland valley groups largely concentrated on agriculture or herding (Focacci, 1974 & 1993; Muñoz, 1981 & 2004).

Several pottery styles existed (with corresponding textile styles), including the Cabuza (Berenguer and Dauelsberg, 1989; Dauelsberg, 1985), Loreto Viejo (Focacci, 1980 & 1981), Maytas (Berenguer and Dauelsberg, 1989), San Miguel, and Gentilar (Focacci, 1980; Stanish, 1991; Rivera, 2008; Schiappacasse *et al.*, 1989). Each of these pottery styles has been associated with a specific ethnic group (Hidalgo and Focacci, 1986; Muñoz, 1993) These pottery styles are found in both coastal and inland valley sites (Focacci, 1974), although each site is reported to have had one pottery style as the predominant type among the pottery wares (Cassman, 1997; Sutter, 2005). The mortuary traditions continued to include stone-lined tombs but adobe brick-lined tombs were also widely used. The seated, flexed position and the wrapping of the body in textiles of various conditions and qualities also continued (Focacci, 1993; Muñoz and Focacci, 1985). A variety of local and exotic grave goods were found among coastal and inland valley sites, including tropical bird feathers and animal products, spondylus shell, and non-local metal ores (Aufderheide *et al.*, 2002; Cassman, 1997; Focacci, 1993; Rivera, 2008). There is evidence of subtle differences in grave good goods among the sites of this period, suggesting status differences may have been present (Cassman, 1997). The pottery and textile evidence was largely believed to be evidence of ethnic differentiation among the sites (Hidalgo and Focacci, 1986; Muñoz, 1993; Ulloa, 1981). Differences in subsistence strategies among these sites are also attributed as additional evidence of ethnic differentiation (Focacci, 1993; Muñoz and Focacci, 1985). However, recent studies suggest that these were instead markers of social status (Cassman, 1997 & 2000; Sutter, 2005).

The Late Period began in AD 1476 and ended at the time of Spanish Conquest of the region (AD 1532). This period is characterized by control of the region by the Inca Empire (Goldstein, 2005; Piazza, 1981; Rivera, 2008; Santoro, 1981). Several *pukaras* (fortresses) and *tambos* (Inca messenger stations) were built (Goldstein, 2005; Rivera, 2008). Inca, Gentilar, and Estuquina ceramic styles were the dominant ceramic traditions (Focacci, 1981a; Piazza, 1981; Santoro, 1981). Focacci (1980) attributes the presence of Inca ceramics as evidence of the existence of Inca *mitimaqs* (colonists) in the region. Despite this Inca influence or colonization, the northern Chilean groups continued to practice agro-maritime subsistence strategies, localized trading patterns, and mortuary customs in similar patterns to the preceding period (Muñoz, 1981b). It is believed that similar ethnic and status differentiations that were present in the preceding Regional Development Period would exist in this period as the Inca presence in the region did not greatly change the cultural landscape of the region.

5.2 Hypotheses

Although many other cultural motivations for practicing ACM likely existed (as mentioned above), the purpose of this study is to examine the cultural motivations of ACM among ancient populations of northern Chile by examining the two most popular hypotheses: (1) that ACM was practiced as a marker of social status, and (2) that ACM was practiced by ancient Andean societies as marker of ethnic identity.

5.2.1 Hypothesis 1

(a) The first hypothesis that is tested here is the assertion that there exists a correlation between the presence of ACM (all styles combined) and the quantity and/or quality of grave goods in burials from the region. The existence of such a pattern could be interpreted in terms of ACM being restricted to individuals of certain social status or that ACM was a marker of social differentiation. Based on ethnohistoric records (de las Casas, 1892 [1561]; Torquemada, 1995 [1557-1664]), ACM is associated with higher social status. Therefore, it is expected that modified individuals will consistently present with a higher quantity and/or quality of grave goods as compared to unmodified individuals on each of the sites for which information is available (Table 5.1).

(b) In further testing this first hypothesis, an examination of the existence of a correlation between specific ACM styles using established typologies from Hrdlička, (1912), Dembo and Imbelloni (1938), and Allison *et al.* (1981) and quantity and/or quality of grave goods will be conducted for the purpose of determining if specific patterns exist that could be interpreted in terms of specific ACM styles being restricted to individuals of certain social status. It is expected that there will be a difference in the quantity and quality of grave goods among the various ACM styles indicating the presence of social differentiation (Table 5.1).

5.2.2 Hypothesis 2

The second hypothesis that will be tested here is the claim that there is a geographic clustering of ACM styles by sites and/or regions in northern Chile, a pattern which could be interpreted in terms of ethnic groups practicing distinct styles of ACM. If ACM is a marker of ethnicity, it is expected that each site will exhibit a majority ACM style (Table 5.1). There may also be a common ACM style among clusters of sites by region (e.g. among coastal valley and inland valley sites). Absence of statistically significant differences in ACM styles among sites would instead indicate that other motivations were at play. Alternative hypotheses will be explored based on the distribution of the data, as necessary.

Table 5.1: Expectations for Hypothesis 1 (a & b) and Hypothesis 2

Hypothesis	Expectation
1a: A correlation between the presence of ACM (all styles combined) and the quantity and/or quality of grave goods in burials will exist, suggestive of ACM being a marker of *social status*.	Modified individuals will present with higher quantities and/or qualities of grave goods as compared to unmodified individuals.
1b: A correlation between specific ACM styles and quantity and/or quality of grave goods in burials will exist, suggestive of specific ACM styles being a marker of either high or low *social status*.	Specific styles will present with differential quantities and/or qualities of grave goods
2: Geographic clustering of ACM styles by site and/or regions in northern Chile could be indicative of groups exhibiting different *ethnicities* as defined by previous studies identifying ethnic differentiation by site or region from material cultural evidence.	Each site will exhibit a majority ACM style, indicating ACM was used as a marker of ethnicity. There may be a dominant ACM style by region where sites share similar material culture.
	Formative Period: Dominant ACM styles by region but not site based on archaeological evidence (e.g. common subsistence strategies, material culture evidence, particularly pottery, and mortuary traditions among groups by region).
	Regional Development Period: Dominant ACM styles by site but not region based on archaeological evidence demonstrating “ethnic” material culture (e.g. pottery and textile) differences by site.
	Late Period: Dominant ACM styles by site but not region as it is expected ethnic differentiation from previous period continued into this period.

5.3 Methodology

A total sample of 435 individuals from both coastal and inland valley environments of the Azapa, Camarones, and Lluta Valleys was utilized, although the overall sample size varied for the purpose of hypothesis testing. The samples were derived from Formative to Late Period collections housed at the Museo Arqueologico de San Miguel de Azapa in Arica, Chile (Table 5.2). No data are available for the Middle Horizon Period and the Archaic Period was excluded due to lack of a large enough sample of modified crania for testing. Modified and unmodified adult and juvenile crania were surveyed.

Table 5.2: Sample Make Up

Period	Cultural Phases	Dates	Coastal Sites	Inland Sites
Late Period	Gentilar Inca	A.D. 1476-1532	Camarones 8 and Camarones 9	Azapa 8, Camarones 8, Camarones 9, Lluta 54
Regional Development	Chiribaya Maytas Maytas-Chiribaya San Miguel	A.D. 1100-1476	None	Azapa 6, Azapa 11, Azapa 71, Azapa 76, Azapa 140, Azapa 141
Middle Horizon	Tiwanaku Influence	A.D. 500-1100	None	None
Formative Period	Alto Ramirez Azapa El Morro El Laucho	1500 B.C.-A.D. 500	Playa Miller 7	Azapa 70, Azapa 75, Quiani 7
Archaic Period	Chinchorro Quiani	8000-1500 B.C.	None	None

A general inventory was completed, which included the collection of information concerning sex and age-at-death for all applicable individuals. Sex determinations were based on cranial morphology methods (Acsadi and Nemeskeri, 1970; Buikstra and Ubelaker, 1994), as postcranial remains were unavailable at time of data collection, and were only undertaken for adults as juveniles in this sample cannot be accurately sexed (Sutter, 2003). Specific age-at-death determinations were unable to be determined since the cranial suture closure methods could not be used since modification can affect its accuracy (O'Brien and Sensor, 2008) and no pelvic bones were available to survey. Adult individuals with erupted third molars were therefore categorized as "adults of unknown age". Other aging methods based on the cranium (e.g. dental wear) could not be used due to broken or missing materials or the inability to make observations (e.g. obstruction due to presence of soft tissue). The primary method used to age juvenile individuals was the dental formation standard derived from Ubelaker (1999). Dental formation patterns for each individual were discerned through radiographic analyses. X-rays were taken on Kodak T-Mat G/RA Diagnostic Film with a Shimadzu EZY-RAD VA-125P-CH X-ray machine. X-rays were taken by the author and affiliated Radiology Department faculty and students from the Universidad de Tarapaca. Analysis of the x-rays was completed by the author at The University of Western Ontario.

Different forms of cranial modification were scored based on a nested typology created by the author (see Chapter 2). The nested typology combined modification typologies created by Hrdlička (1912) (Level 1), Dembo and Imbelloni (1938) (Level 2), and Allison *et al.* (1981) (Level 3). The collection of these typologies was used in order to cover the breadth of diversity of modification types and devices noted in the region as identified previously by Allison *et al.* (1981) and to allow for ease of comparison with past and future studies on ACM among Andean groups. Additionally, the use of the nested typology would allow for testing which of the typologies would be best for use in these types of analyses. It is important to note that upon examination of the crania not all of the identified Level 3 types collapsed perfectly into the Level 1 and 2 types (see Chapter 2), which could be attributed to the discrepancy in the number of modification styles (n=14) and modification devices (n=11) in the region (Allison *et al*., 1981). Multiple devices may have been used to create the same style, or practitioners opted to mimic specific styles for particular reasons. Cranial modifications were scored visually by the author based on criteria outlined by the creators of each typology. Crania were first determined to be either modified or unmodified based on macroscopic examination, and in cases where modification was present, the crania were further scored based on the criteria outlined by the authors of the different typologies (Allison *et al.*, 1981; Dembo-Imbelloni, 1938; Hrdlička, 1912).

Grave good data were utilized in this study for the purpose of testing the first hypothesis (ACM as a marker of social status). Due to limitations of the information available at the museum, however, these types of data were only available for the Regional Development Period as this is the only period with accurate associations between individuals and grave goods. These data were collected and provided by Vicki Cassman (pers. comm., 2009), who generously allowed access to her data for the purposes of completing this study. The inventory numbers for the sample used in this study and those provided by Cassman were similar, allowing for comparison of grave goods by site and ACM styles.

The grave good data were analyzed based on methods previously used by scholars (Millaire, 2002; Tainter, 1978; Tainter and Cordy, 1977). These data were first divided by grave good quality and grave good quantity for each individual's burial. The grave good quantity data were determined based on the number of grave goods present. Present artifacts were counted and tallied for each burial. The cumulative total of the grave goods was the individual scores for each burial. Grave good quality was measured using an energy expenditure index for each burial. Energy expenditure is the categorization of the relative energy expended on the creation or procurement of specific artifacts or materials used in the creation of the artifact (Tainter, 1978; Tainter and Cordy, 1977). Artifacts that require a specific effort in creation or procurement are numerically scored, while artifacts that require little to no effort in creation or procurement are not included. The cumulative scores for each burial based on the number of energy expenditure artifacts present were then compared in order to determine the relative social status of individuals associated with those cumulative scores. For the purposes of this research and in consultation with Dr. Jean-Francois Millaire (pers comm., 2012), the following grave goods were used in calculating the energy expenditure for each grave: textiles, ceramics, exotic/non-local goods, and previously identified "high status" items. These grave goods were scored differently based on the presence/absence and the quantity of items present (Table 5.3). Textiles, which were the most abundant, were scored on a range based on the number present in each burial. These ranges were arbitrarily chosen in order to keep the overall energy expenditure scores consistent among the majority of categories. High status items were the sparsest grave good and were scored based on the presence or absence of the items. The remaining grave goods were scored based on the number of each item present in the burial, with a maximum score of 4. Graves received a score of zero for each category if no applicable grave goods were present. Graves received an overall score of zero when no energy expenditure grave goods were present within the grave.

Table 5.3: Classifications of Energy Expenditure Artifacts

Energy Expenditure Artifact Classifications	**Types of Artifacts Included**	**Numeric Score**
Textiles	Bag, Blanket, Ceremonial Cloth, Colored Cloth, Shirt, Sling	0=0 items 1=1-2 items 2=3-4 items 3=5-7 items 4=8+ items
Ceramics	Culturally Specific (e.g. Cabuza, Loreto Viejo, Maytas, San Miguel, Sobraya), Decorated & Undecorated Jar, Kero, Olla, Puco	0=0 items 1=1 items 2=2 items 3=3 items 4=4 items
Exotic Items	Amazonian Bird Feathers, Carved Wooden Spoons & Items, Leather Rope, Leather Sandals, Leather Strip, Vichuña Items	0=0 items 1=1 items 2=2 items 3=3 items 4=4 items
High Status Items	4-Pointed Hats, Hallucinogenic Items, Jewelry	0=Absent 1=Present

The grave good quantity and grave good energy expenditure data of all individuals were compared across all the sites and among all the ACM styles identified in the nested typology with box plots in order to identify significant patterns. These data were then statistically tested with either the Pearson's Correlation, Student's t-test, or ANOVA tests. These tests were used to examine if a significant relation exists among the variables. These analyses were completed via the SSPS 19 program.

For the purposes of testing the second hypothesis, ACM as a marker of ethnicity, the distribution of ACM styles was surveyed by sites, and then by region, within each valley. "Region", for the purpose of this research, is defined as either the coastal valley or inland valley, which should not be confused with the traditional coast and highland differentiation used within Andean contexts. These data were divided by each typology and tested for each period. The expectations were derived in a contingency table where the row total was multiplied by the column total and divided by the sample total. The result was rounded up or down to the nearest whole number accordingly. The Chi-square test, a goodness of fit test designed to examine association among several variables, was used to test these data in order to determine if the ACM distributions by sites and regions were statistically different, which could be suggestive of ethnic differences among these groups. Expected values are demonstrated in the Chi-square tables, and these expected values were calculated by multiplying row and column totals and dividing by total sample. The ACM data were also compared by biological sex in order to further examine the ethnicity hypothesis.

5.4 Results & Discussion

5.4.1 Hypothesis 1(a & b): ACM is a Marker of Social Status

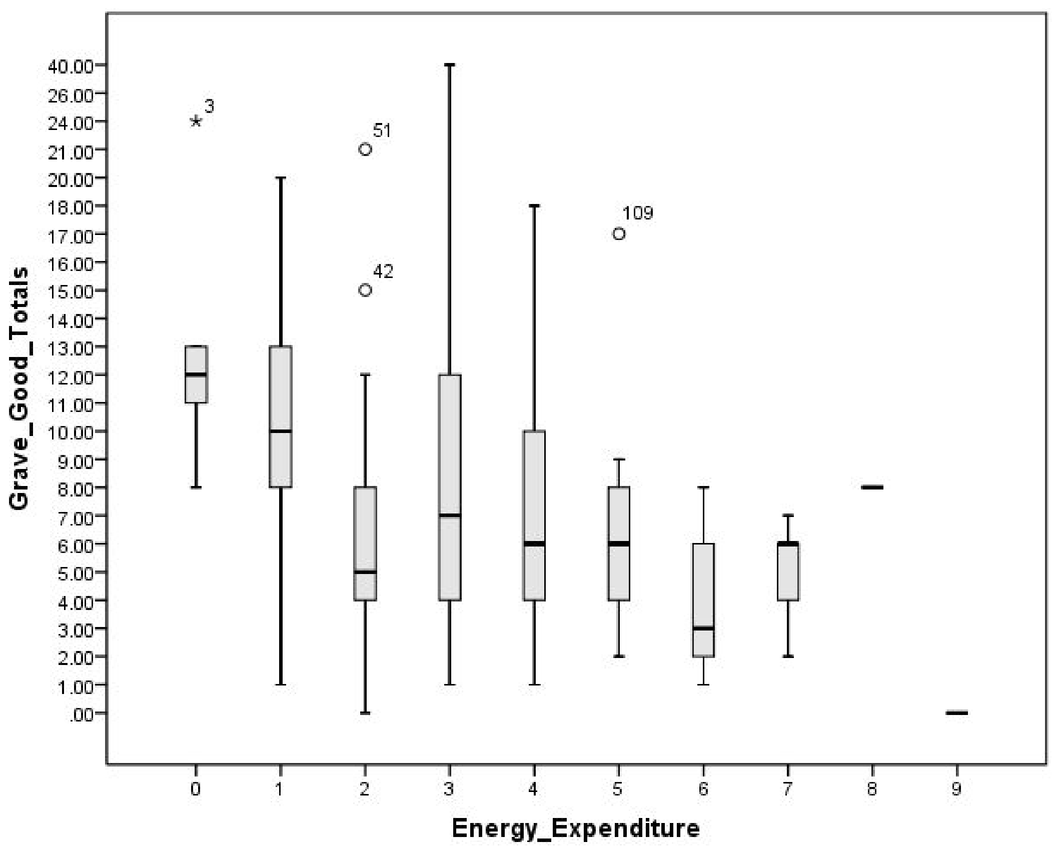
The purpose of Hypothesis 1 is to test the assertion that there exists an association between the quantity and/or quality of grave goods in burials from the region and A) ACM presence (all styles combined) and B) the various ACM styles. Based on the ethnohistoric literature and that ACM requires an expenditure of energy, it was expected that modified individuals would present with larger quantities *and* higher quality grave goods (hence higher energy) when compared to unmodified individuals. The Regional Development Period was the only period with grave good data and therefore these are the only data that will be shown here. The data were therefore first tested to determine what the relationship between energy expenditure and grave good quantity data for all sites was. These data were compared and tested with the Pearson Correlation test, and the results demonstrated a negative correlation amongst the data that were statistically significantly different between the two data sets (Table 5.4). The data were then plotted in a box plot and it was shown that individuals with more grave goods had lower energy expenditure values (Figure 5.2), which is in agreement with an assessment previously reached by Cassman (1997). Upon further examination it was found that burials with few or no quality offerings (ceramic vessels, textiles, etc.) were often found with many utilitarian items (e.g. food stuffs, fishing gear, spindle whorls, etc.), something which could easily skew analyses based on the overall quantity of objects present in the grave. Based on this result, it was decided that only energy expenditure data would be used to test Hypothesis 1.

Table 5.4: Comparison of Energy Expenditure and Grave Good Quantity Data (Pearson's Correlation)

		Energy Expenditure	Grave Good Totals
Energy Expenditure	Pearson Correlation	1	-.298**
	Sig. (2-tailed)		.001
	N	123	123
Grave Good Totals	Pearson Correlation	-.298**	1
	Sig. (2-tailed)	.001	
	N	123	123

***Correlation is significant at the .001 level.*

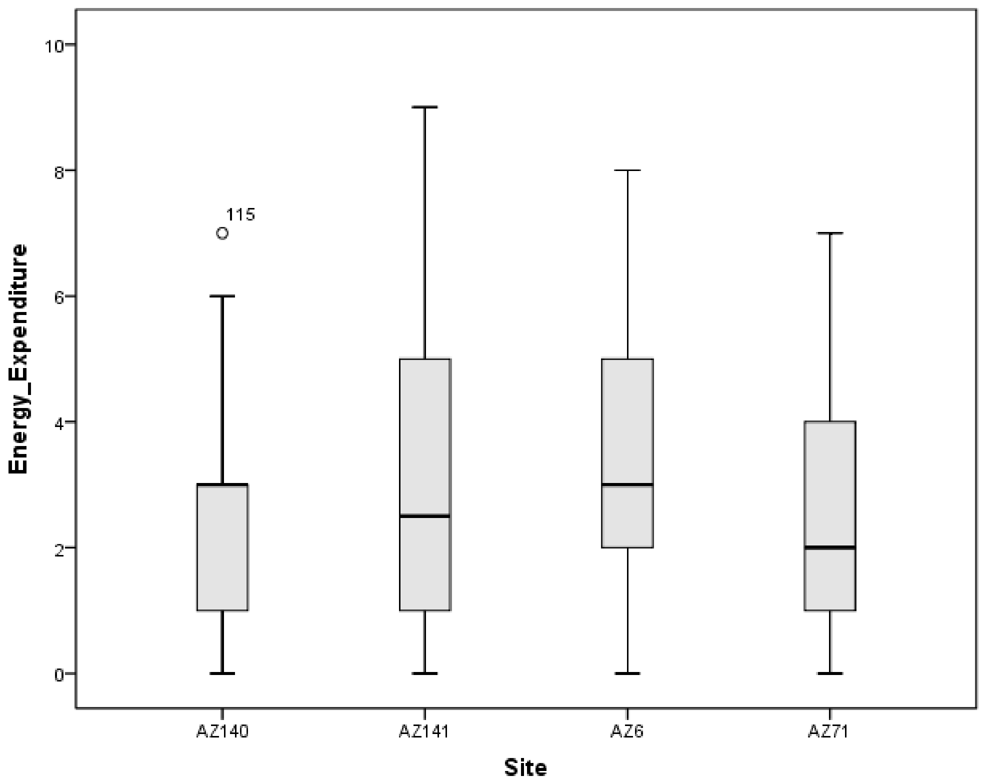
Figure 5.2: Box Plot of Grave Good Quantity by Energy Expenditure Data



The data were then tested to determine if energy expenditure differences existed among the Regional Development Period inland valley sites with testable grave good data.

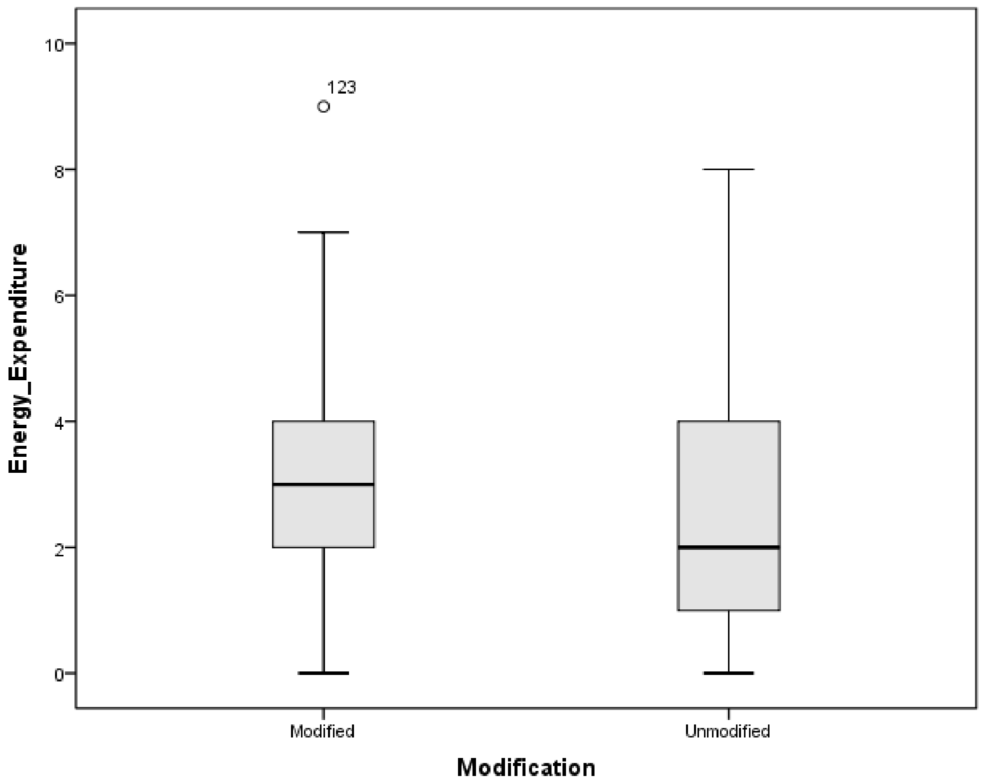
There were insufficient coastal valley data to test for this analysis, and therefore these data were excluded from the analysis. As seen on Figure 5.3, data from the Azapa 141 site exhibit the widest range of energy expenditures (0-9) while data from the Azapa 71 and 140 exhibit the smallest ranges of energy expenditures (0-7). Overall, however, the ranges and means demonstrated by these box plots show little difference among the sites. Further statistical testing with the ANOVA test reveal that the energy expenditure ranges and means are largely the same as no statistically significant differences exist among these sites (P= .0.176)).

Figure 5.3: Box Plot of Energy Expenditure Data by Site



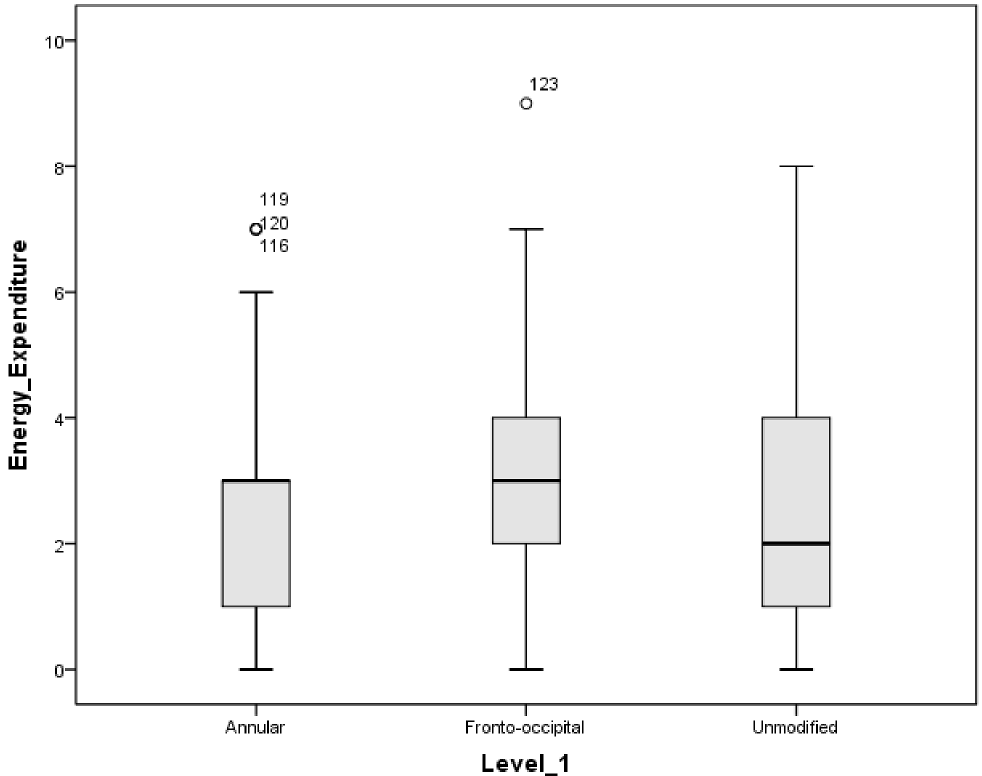
Based on this result, all of the data were grouped together as one data set and are presented as such through the remainder of this chapter. The energy expenditure data were then compared by modification presence (all forms combined) or absence. Based on the data distribution of Figure 5.4, modified individuals demonstrate the smallest range of energy expenditure data, but these data do demonstrate an overall higher mean in energy expenditure as compared to the unmodified individuals. The Student's t-test demonstrates no statistically significant differences among these data (P= 0.380).

Figure 5.4: Box Plot of Energy Expenditures by Modification Presence or Absence



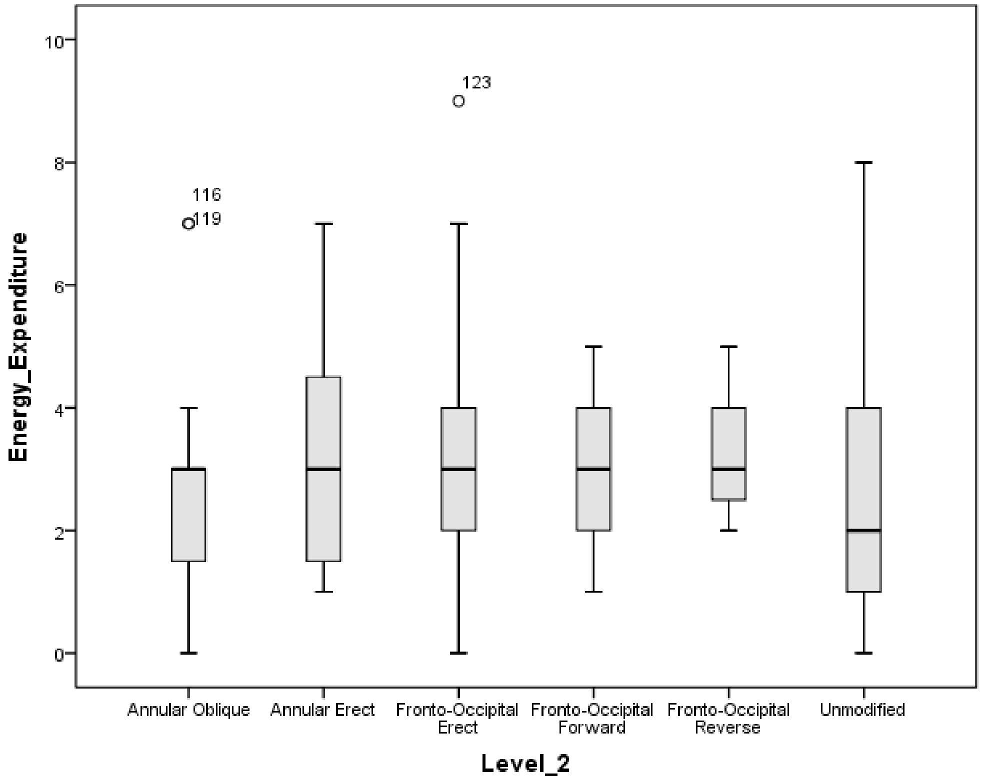
Further division of the data into the Level 1 typology demonstrated similar trends to the above grouped modified/unmodified data. Both annularly and fronto-occipitally modified individuals demonstrate higher mean energy expenditures than unmodified individuals but only fronto-occipitally modified individuals demonstrate more of a range than the unmodified sample (Figure 5.5). There is no difference in the mean energy expenditure between annularly and fronto-occipitally modified individuals, although annularly modified individuals show a smaller range of variation than the fronto-occipitally modified individuals. The ANOVA test failed to demonstrate a statistically significant difference among these means (P= 0.235). A Student's t-test of just the fronto-occipitally modified versus annularly modified individuals did not demonstrate a statistically significant difference, revealing no difference in energy expenditure data between these two modification styles (P= 0.735).

Figure 5.5: Box Plot of Energy Expenditures by Level 1 Modification Styles



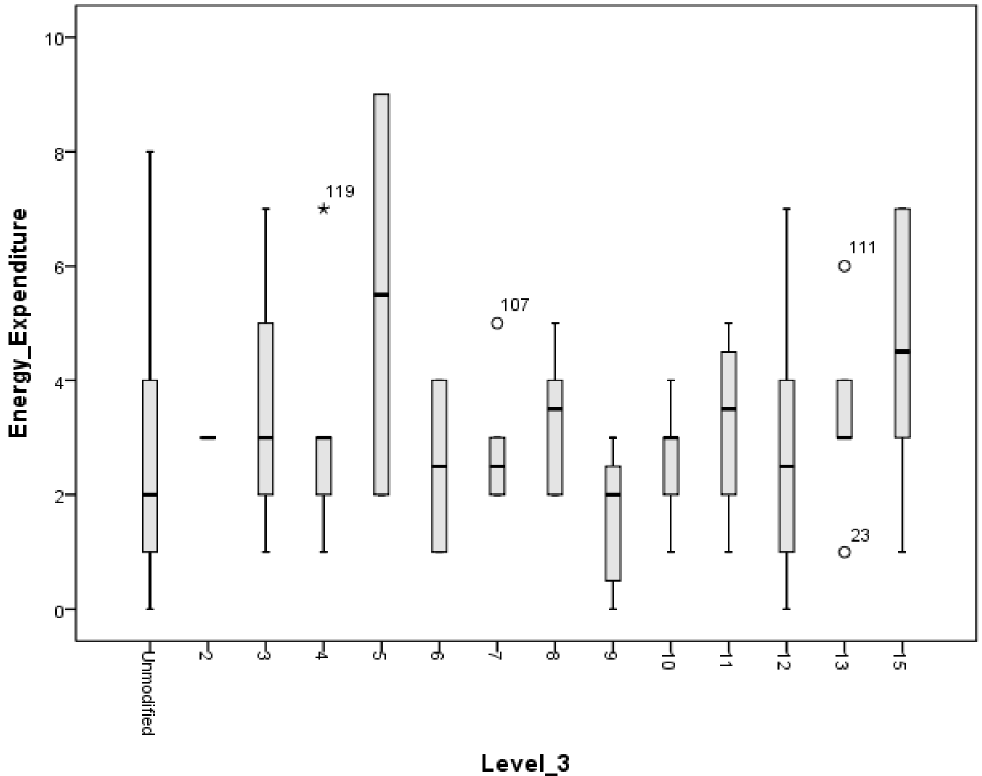
When the data were divided by the Level 2 ACM styles, similar results are present (Figure 5.6). There continues to be no difference in the means of the energy expenditures among all the ACM styles, and all modified groups continue to show slightly higher means than the unmodified sample. Fronto-occipital erect and unmodified individuals have the greatest range in energy expenditures, which surpasses the ranges of the remaining samples. The highest energy expenditure value of the fronto-occipital erect modified individuals is the same as that of the annular erect modified individuals. The ANOVA test did not produce statistically significant differences among these means (P= 0.246), and removal of the unmodified data did not change this result (P= 0.636).

Figure 5.6: Box Plot of Energy Expenditures by Level 2 Modification Styles



Overall, the modified individuals of the Level 3 typology demonstrated higher energy expenditure means than the unmodified individuals, with the exception of individuals with Style 9 modified crania (Figure 5.7). Several modified individuals demonstrate similar means in energy expenditure data but Styles 5 and 15 demonstrate the highest energy expenditure means. Style 5 also demonstrates the highest energy expenditure overall but the greatest range in the data is present among the unmodified data. When the data are examined with the ANOVA there remains no statistically significant differences among these data (P= 0.454). The removal of the unmodified data did not affect this result (P= 0.600).

Figure 5.7: Box Plot of Energy Expenditures by Level 3 Modification Styles



Based on the above results, there are no statistically significant differences in energy expenditure data present between modified and unmodified individuals. This result does not support the status hypothesis and instead demonstrates that unmodified and modified individuals were buried with artifacts indicating similar levels of energy investment, something which suggests that ACM was not used to express differences in social status in the Regional Development Period. Further examination of the data, particularly among the various ACM typologies, shows no statistically significant differences amongst the modification styles-be they compared with or without unmodified cranial data. Overall, these results do not support the hypothesis that ACM was a marker of social status in the Regional Development Period. As there were insufficient grave good data available for the remaining periods, this hypothesis cannot be tested for these periods.

5.4.2 Hypothesis 2: ACM as a Marker of Ethnicity

The purpose of hypothesis 2 was to examine claims that ACM was a marker of ethnicity based on the geographical distribution of ACM styles. There was an expectation that if ACM was being used as a marker of ethnicity that each site and possibly region would present with a particular ACM style as the majority style. The data were analyzed by period since ACM style preferences were likely affected by historical events.

5.4.2.1 Formative Period

During the Formative Period, three sites were surveyed: the coastal valley site of Playa Miller 7, a site characterized by El Laucho ceramics, and the inland valley sites of Azapa 70 and Azapa 75, both sites characterized by Alto Ramirez ceramics. Based on the ceramic associations, it is assumed that these sites are similarly contemporaneous, but these individuals from these sites should differentiate themselves ethnically based on the ceramic associations of the area (Focacci, 1974; Focacci and Chacon, 1989; Llagostera, 2010; Muñoz, 1989; Santoro, 1980a, b, & c). The ACM style data were first divided among these sites and trends were examined and tested with the Chi-square. At Playa Miller 7, the annular style was the most prevalent ACM style of the Level 1 typology, making up 88% of the sample, and the annular oblique style is the majority style of the Level 2 typology at the same site, making up 63% of the sample. At Azapa 70 the same ACM styles were the most prevalent, making up 86% and 57% of the sample respectively. The fronto-occipital and fronto-occipital erect styles were the majority style at Azapa 75, with the fronto-occipital style making up 94% of the sample and fronto-occipital erect making up 76% of the sample (Tables 5.5 & 5.6). There are some similarities in styles among the Level 3 typology among all sites, but these are at reduced incidences with many cell counts less than 5, casting doubt on the utility of statistical analysis with this typology and its ability to test this hypothesis (Table 5.7). Statistical testing by all three typologies demonstrates that the prevalence of types at each site differs significantly from the expectations.

An examination of the data at the regional level, which combines Azapa 70 and 75, was also completed based on the previous interpretations by scholars suggestive of differences among coastal and inland valley groups. This analysis shows a preference among the coastal valley group toward annular, at 88%, and annular oblique, at 63%, styles, but the overall preference among the inland valley groups is fronto-occipital, at 70%, and fronto-occipital erect, at 57%, styles, masking the difference in ACM style dominance of these sites (Tables 5.8 and 5.9). There were similar trends in the Level 3 typological data, with coastal valley groups exhibiting Style 8 (believed to be a fronto-occipital oblique forward variant) as the dominant style and inland valley groups exhibiting Style 7 (believed to be a fronto-occipital erect variant) as the dominant style (Table 5.10). All three typological divisions of these data show significant departure from expectations. Overall the regional distribution of the ACM data does suggest that there were regional preferences in ACM style dominance when the sites are combined, suggestive of a desire of coastal and inland groups to differentiate themselves from each other.

Table 5.5: ACM by Site: Level 1 Typology (Formative Period)

	Coastal Sites	**Inland Sites**		**Total**
	Playa Miller 7	*Azapa 70*	*Azapa 75*	
Annular	(E) 25	(E) 8	(E) 19	52
	(O) 38	(O) 12	(O) 2	
Fronto-Occipital	(E) 18	(E) 6	(E) 14	38
	(O) 5	(O) 2	(O) 31	
Total	43	14	33	90
Chi-Square P-Value: .0001				

E=expected data; O=observed data.

Table 5.6: ACM by Site: Level 2 Typology (Formative Period)

	Coastal Sites	**Inland Sites**		**Total**
	Playa Miller 7	*Azapa 70*	*Azapa 75*	
Annular Oblique	(E) 18	(E) 6	(E) 14	37
	(O) 27	(O) 8	(O) 2	
Annular Erect	(E) 7	(E) 2	(E) 6	15
	(O) 11	(O) 4	(O) 0	
Fronto-Occipital Erect	(E) 14	(E) 5	(E) 11	29
	(O) 2	(O) 2	(O) 25	
Fronto-Occipital Forward	(E) 2	(E) 1	(E) 1	4
	(O) 2	(O) 0	(O) 2	
Fronto-Occipital Reverse	(E) 2	(E) 1	(E) 2	5
	(O) 1	(O) 0	(O) 4	
Total	43	14	33	90
Chi-Square P-Value: .0001				

E=expected data; O=observed data.

Table 5.7: ACM by Site: Level 3 Typology (Formative Period)

	Coastal Sites	**Inland Sites**		**Total**
	Playa Miller 7	*Azapa 70*	*Azapa 75*	
Style 2	(E) 2	(E) 1	(E) 1	4
	(O) 3	(O) 1	(O) 0	
Style 3	(E) 3	(E) 1	(E) 2	6
	(O) 3	(O) 2	(O) 1	
Style 4	(E) 1	(E) 0	(E) 1	3
	(O) 2	(O) 1	(O) 0	
Style 5	(E) 0	(E) 0	(E) 0	1
	(O) 1	(O) 0	(O) 0	
Style 6	(E) 0	(E) 0	(E) 0	1
	(O) 0	(O) 0	(O) 1	
Style 7	(E) 8	(E) 3	(E) 6	17
	(O) 5	(O) 3	(O) 9	
Style 8	(E) 9	(E) 3	(E) 7	18
	(O) 14	(O) 2	(O) 2	
Style 9	(E) 4	(E) 1	(E) 3	9
	(O) 3	(O) 2	(O) 4	
Style 10	(E) 2	(E) 1	(E) 1	4
	(O) 0	(O) 0	(O) 4	
Style 11	(E) 1	(E) 0	(E) 1	3
	(O) 3	(O) 0	(O) 0	
Style 12	(E) 9	(E) 3	(E) 7	19
	(O) 9	(O) 2	(O) 8	
Style 13	(E) 1	(E) 0	(E) 1	2
	(O) 0	(O) 0	(O) 2	
Style 14	(E) 0	(E) 0	(E) 0	0
	(O) 0	(O) 0	(O) 0	
Style 15	(E) 1	(E) 0	(E) 1	3
	(O) 0	(O) 1	(O) 2	
Total	43	14	33	90
Chi-Square P-Value: .022				

E=expected data; O=observed data.

Table 5:8: ACM by Regional Location: Level 1 Typology (Formative Period)

	Coastal Sites	**Inland Sites**	**Total**
Annular	(E) 25	(E) 27	52
	(O) 38	(O) 14	
Fronto-Occipital	(E) 18	(E) 20	38
	(O) 5	(O) 33	
Total	43	47	90
Chi-Square P-Value: .000			

E=expected data; O=observed data.

Table 5.9: ACM by Regional Location: Level 2 Typology (Formative Period)

	Coastal Sites	**Inland Sites**	**Total**
Annular Oblique	(E) 18	(E) 19	37
	(O) 27	(O) 10	
Annular Erect	(E) 7	(E) 8	15
	(O) 11	(O) 4	
Fronto-Occipital Erect	(E) 14	(E) 15	29
	(O) 2	(O) 27	
Fronto-Occipital Forward	(E) 2	(E) 2	4
	(O) 2	(O) 2	
Fronto-Occipital Reverse	(E) 2	(E) 3	5
	(O) 1	(O) 4	
Total	43	47	90
Chi-Square P-Value: .000			

E=expected data; O=observed data.

Table 5.10: ACM by Regional Location: Level 3 Typology (Formative Period)

	Coastal Sites	**Inland Sites**	**Total**
Style 2	(E) 2	(E) 2	4
	(O) 3	(O) 1	
Style 3	(E) 3	(E) 3	6
	(O) 3	(O) 3	
Style 4	(E) 1	(E) 2	3
	(O) 2	(O) 1	
Style 5	(E) 0	(E) 1	1
	(O) 1	(O) 0	
Style 6	(E) 0	(E) 1	1
	(O) 0	(O) 1	
Style 7	(E) 8	(E) 9	17
	(O) 5	(O)12	
Style 8	(E) 9	(E) 9	18
	(O) 14	(O) 4	
Style 9	(E) 4	(E) 5	9
	(O) 3	(O) 6	
Style 10	(E) 2	(E) 2	4
	(O) 0	(O) 4	
Style 11	(E) 1	(E) 2	3
	(O) 3	(O) 0	
Style 12	(E) 9	(E) 10	19
	(O) 9	(O) 10	
Style 13	(E) 1	(E) 1	2
	(O) 0	(O) 2	
Style 14	(E) 0	(E) 0	0
	(O) 0	(O) 0	
Style 15	(E) 1	(E) 2	3
	(O) 0	(O) 3	
Total	43	47	90
Chi-Square P-Value: .002			

E=expected data; O=observed data.

An examination of the differences of ACM styles among the sexes of these groups combined show no significant differences in all the ACM styles used (Tables 5.11-513.), suggesting that sex was not a factor determining ACM style choice.

Table 5.11: ACM by Sex (Level 1 Typology)

	Males	Females	Indeterminate	Total
Annular	(E) 24	(E) 21	(E) 2	47
	(O) 26	(O) 18	(O) 3	
Fronto-Occipital	(E) 14	(E) 12	(E) 1	28
	(O) 13	(O) 14	(O) 1	
Unmodified	(E) 22	(E) 19	(E) 0	42
	(O) 21	(O) 20	(O) 1	
Total	60	52	5	117
Chi-Square P-Value: .763				

E=expected data; O=observed data.

Table 5.12: ACM by Sex (Level 2 Typology)

	Males	Females	Indeterminate	Total
Annular Oblique	(E) 17	(E) 15	(E) 1	33
	(O) 20	(O) 10	(O) 3	
Annular Erect	(E) 7	(E) 6	(E) 1	14
	(O) 6	(O) 8	(O) 0	
Fronto-Occipital Erect	(E) 9	(E) 8	(E) 1	18
	(O) 9	(O) 8	(O) 1	
Fronto-Occipital Forward	(E) 5	(E) 4	(E) 0	9
	(O) 4	(O) 5	(O) 0	
Fronto-Occipital Reverse	(E) 1	(E) 0	(E) 0	1
	(O) 0	(O) 1	(O) 0	
Unmodified	(E) 22	(E) 19	(E) 2	42
	(O) 21	(O) 20	(O) 1	
Total	60	52	5	117
Chi-Square P-Value: .183				

E=expected data; O=observed data.

Table 5.13: ACM by Sex (Level 3 Typology)

	Males	Females	Indeterminate	Total
Unmodified	(E) 18	(E) 16	(E) 2	36
	(O) 17	(O) 18	(O) 1	
Style 2	(E) 2	(E) 1	(E) 0	3
	(O) 2	(O) 1	(O) 0	
Style 3	(E) 3	(E) 3	(E) 0	6
	(O) 4	(O) 2	(O) 0	
Style 4	(E) 2	(E) 1	(E) 0	3
	(O) 2	(O) 1	(O) 0	
Style 5	(E) 1	(E) 0	(E) 0	1
	(O) 0	(O) 1	(O) 0	
Style 6	(E) 1	(E) 0	(E) 0	1
	(O) 0	(O) 1	(O) 0	
Style 7	(E) 8	(E) 7	(E) 1	16
	(O) 6	(O) 7	(O) 3	
Style 8	(E) 13	(E) 12	(E) 1	26
	(O) 17	(O) 9	(O) 0	
Style 9	(E) 3	(E) 2	(E) 0	5
	(O) 2	(O) 3	(O) 0	
Style 10	(E) 2	(E) 1	(E) 0	3
	(O) 2	(O) 1	(O) 0	
Style 11	(E) 1	(E) 1	(E) 0	2
	(O) 0	(O) 2	(O) 0	
Style 12	(E) 6	(E) 5	(E) 1	12
	(O) 6	(O) 5	(O) 1	
Style 13	(E) 1	(E) 1	(E) 0	2
	(O) 2	(O) 0	(O) 0	
Style 14	(E) 0	(E) 0	(E) 0	0
	(O) 0	(O) 0	(O) 0	
Style 15	(E) 1	(E) 0	(E) 0	1
	(O) 0	(O) 1	(O) 0	
Total	60	52	5	117
Chi-Square P-Value: .651				

E=expected data; O=observed data.

These data seem to suggest that the annular modification styles were the dominant modification style for the coastal valley site of Playa Miller 7, an El Laucho site, and inland valley site of Azapa 70, an Alto Ramirez site, while the fronto-occipital modification styles was the dominant modification style for the inland valley site of Azapa 75, also an Alto Ramirez site. These results do not support the expectation that a dominant regional style exists but do support the existence of a dominant ACM style by site (see Table 5.1). The material culture evidence was interpreted in the past as a marker of ethnic differentiation between coastal and inland valley groups (Focacci, 1974; Focacci and Chacon, 1989; Llagostera, 2010, Muñoz, 1989; Santoro, 1980a & b), but the

ACM data do not follow this trend. Therefore, ACM may not have been used as a marker of regional ethnic identity, but the results do not rule out ACM as a marker of ethnicity by site. At this time there is no evidence to support this claim as Playa Miller 7 and Azapa 70 have practice different cultural practices (e.g. material culture, subsistence strategies, etc.) and further study of the material culture evidence would be necessary to support this assertion. Alternatively, ACM may have been used as a marker of a different identity, such as social status or sex. The social status hypothesis cannot be tested herein as there are insufficient grave good data to test the social status hypothesis, and sex was ruled out as a motivation based on the results presented above (Tables 5.11-13). ACM may have also served an entirely different purpose as previously suggested by scholars (e.g. instilling personality characteristics, improving health, etc.) (cf. Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; Dingwall, 1931; Morton, 1839; Torquemada, 1995 [1557-1664]; Stewart, 1943; Weiss, 1961). Further study into this matter is necessary to clarify the motivation(s) that drove the practice of ACM during this period.

5.4.2.2 Regional Development Period

During the Regional Development Period, there were six inland valley sites surveyed, and these included the Azapa 6, Azapa 11, Azapa 71, Azapa 76, Azapa 140, and Azapa 141 sites. No coastal valley sites were available for analysis at the time of data collection. ACM styles of the Level 1 typology were compared by site, and the remaining typologies were not used herein as too many low cell counts existed, weakening the statistical strength of these results. The most common modification style is fronto-occipital, 67%-89% at all sites, with the exception of Azapa 76, which demonstrated majority styles for the annular (75%) (Tables 5.14). The ACM style data were then examined based on their distribution by sex, and the styles were fairly equally distributed among the sexes (Tables 5.15). There were no statistically significant differences present among these data.

Table 5.14: ACM by Site: Level 1 Typology (Regional Development Period)

	Inland Sites						**Total**
	Azapa 11	*Azapa 140*	*Azapa 141*	*Azapa 6*	*Azapa 71*	*Azapa 76*	
Annular	(E) 1	(E) 9	(E) 3	(E) 6	(E) 7	(E) 1	28
	(O) 1	(O) 11	(O) 1	(O) 5	(O) 7	(O) 3	
Fronto-Occipital	(E) 2	(E) 23	(E) 6	(E) 15	(E) 17	(E) 3	66
	(O) 2	(O) 22	(O) 8	(O) 16	(O) 17	(O) 1	
Total	3	33	9	21	24	4	94
Chi-Square P-Value: .3072							

E=expected data; O=observed data.

Table 5.15: ACM by Sex (Level 1 Typology)

	Males	Females	Indeterminate	Total
Annular	(E) 7	(E) 10	(E) 1	19
	(O) 9	(O) 10	(O) 0	
Fronto-Occipital	(E) 20	(E) 28	(E) 4	52
	(O) 14	(O) 32	(O) 6	
Unmodified	(E) 37	(E) 52	(E) 7	96
	(O) 42	(O) 48	(O) 6	
Total	65	90	12	167
Chi-Square P-Value: .111				

E=expected data; O=observed data.

These results do not meet the expectation for the Regional Development Period as it was expected that each site would exhibit a dominant ACM style, representing different ethnic groups by site, following Rostworoski (1986) (Table 5.1). The common ACM styles among these various inland valley sites are, however, suggestive of one of two things: either A) a regional ACM style shared among the inland valley sites/groups (with ACM serving as a marker of regional ethnicity), or B) ACM served a different purpose other than ethnicity. Based on the lack of coastal data for comparison, it is difficult to determine if a regional ethnic differentiation was present during this period. Future studies utilizing these data are necessary to examine this conclusion further. Analysis of the social status hypothesis has already ruled out ACM as a marker of social status, which partially rejects conclusion B. It is beyond the scope of this study to examine alternative hypotheses outside of the social status and ethnicity hypotheses outlined here, although ACM may have been practiced for an entirely different purpose or a myriad of purposes.

5.4.2.3 Late Period

For the Late Period, four sites were surveyed: coastal valley sites of Camarones 8 and Camarones 9 and inland valley sites of Azapa 8 and Lluta 54. Again, only the Level 1 typology was used as the Level 2 and 3 typologies produced statistically weakened results due to low cell counts. The most common ACM style at Camarones 8 and Camarones 9 was fronto-occipital, at 83% and 67% respectively (Tables 5.16). The most common ACM style among Azapa 8 and Lluta 54 were the annular style at 50% and 70% respectively (Table 5.16). Overall, there appear to be regional patterns in the data as both coastal valley and inland valley sites share similar styles (Tables 5.17). The data distributions for the Level 1 typology when divided by the site and regional levels demonstrated statistically significant differences. The ACM styles did not demonstrate any statistically significant associations with sex (Table 5.18). It is important to note that overall the incidences of all of these ACM styles were low, producing several cells with counts less than 5. These low cell counts make these results suspect as they weaken the statistical strength of each analysis.

Table 5:16: ACM by Site: Level 1 Typology (Late Period)

	Coastal Sites		**Inland Sites**		**Total**
	Camarones 8	*Camarones 9*	*Lluta 54*	*Azapa 8*	
Annular	(E) 4	(E) 4	(E) 4	(E) 11	23
	(O) 1	(O) 2	(O) 5	(O) 15	
Fronto-Occipital	(E) 2	(E) 2	(E) 2	(E) 6	12
	(O) 5	(O) 4	(O) 1	(O) 2	
Total	6	6	6	17	35
Chi-Square P-Value: .003					

E=expected data; O=observed data.

Table 5:17: ACM by Regional Location: Level 1 Typology (Late Period)

	Coastal Sites	**Inland Sites**	
Annular	(E) 8	(E) 15	23
	(O) 3	(O) 20	
Fronto-Occipital	(E) 4	(E) 8	12
	(O) 9	(O) 3	
Total	12	23	35
Chi-Square P-Value: .000			

E=expected data; O=observed data.

Table 5.18: ACM by Sex Typology (Level 1)

	Males	Females	Indeterminate	Total
Annular	(E) 9	(E) 8	(E) 2	19
	(O) 12	(O) 6	(O) 1	
Fronto-Occipital	(E) 1	(E) 1	(E) 0	3
	(O) 1	(O) 2	(O) 0	
Unmodified	(E) 16	(E) 15	(E) 3	34
	(O) 13	(O) 17	(O) 4	
Total	26	25	5	56
Chi-Square P-Value: .423				

E=expected data; O=observed data.

These data emphasize a regional ACM style versus individual site style(s), which does not meet the expectations of the data based on archaeological evidence that suggests that ethnic identity would be expressed differently at each site (Table 5.1). The results of these analyses also demonstrate a switch in the predominant ACM styles that were previously seen in this region, with coastal valley groups displaying a majority of fronto-occipital styles and inland valley groups a majority of annular styles. This switch in ACM style trends matches the ethnohistorical accounts, which suggest that fronto-occipital modification was a coastal style and annular modification a highland style (Diez de San Miguel, 1964 [1567]), and it could be the result of Inca control of this region. Inca control of this region could have dictated that the local populations switch their modification preferences in order to conform with the Inca ideals, or, as was common during this period and previously cited by Focacci (1980), the Inca could have moved new populations into the region and displaced the original local populations to another region of their empire. Further study is necessary to test of these hypotheses. Overall, these analyses support the ACM as a marker of ethnicity hypothesis.

Overall, with the exception of the Late Period, ACM does not appear to have been a marker of ethnicity as expected based on previous interpretations of the archaeological evidence from this region (Table 5.19). ACM style patterns for the Formative Period demonstrate that ACM styles were similar between two sites, one coastal valley site and one inland valley site, negating the possibility of a regional ethnic identity. ACM may have served as a marker of ethnicity in a different way (e.g. by site), but this explanation may be unlikely since the sites do not share similar cultural practices. The social status hypothesis cannot be tested for this period as sufficient grave good data is not readily available at this time. Therefore, ACM as a marker of a different identity (e.g. social status) or ACM serving an entirely different purpose (e.g. instillation of personality characteristics) cannot be ruled out at this time. Analysis of the Regional Development Period data also did not meet the expectations of ethnicity based on previous archaeological interpretations, which suggested that ethnic differences existed by site. ACM styles were consistently similar across all sites, which could be indicative of ethnic differentiation at the regional level. Due to the inability to examine coastal valley crania at the time of data collection, it is unclear if such a regional ethnic differentiation existed, and further study into this matter is necessary. There were grave good data available to test the social status hypothesis, but the results from these analyses did not support this hypothesis. It was concluded that ACM may have served as a marker of regional ethnicity or served an alternative purpose not investigated within the scope of this study.

Table 5.19: Expectations and Results

<table>
<tr><th>Hypothesis</th><th>Expectation</th><th>Result</th></tr>
<tr><td>1a: A correlation between the presence of ACM (all styles combined) and the quantity and/or quality of grave goods in burials will exist, suggestive of ACM being a marker of social status.</td><td>Modified individuals will present with higher quantities and/or qualities of grave goods as compared to unmodified individuals.</td><td>EXPECTATION NOT MET

(No relationship between modification and grave good quantity or quality)</td></tr>
<tr><td>1b: A correlation between specific ACM styles and quantity and/or quality of grave goods in burials will exist, suggestive of specific ACM styles being a marker of either high or low social status.</td><td>Specific styles will present with differential quantities and/or qualities of grave goods</td><td>EXPECTATION NOT MET

(No relationship among ACM styles and grave good quantity and quality)</td></tr>
<tr><td rowspan="4">2: Geographic clustering of ACM styles by site and/or regions in northern Chile could be indicative of groups exhibiting different ethnicities as defined by previous studies identifying ethnic differentiation by site or region from material cultural evidence.</td><td>Each site will exhibit a majority ACM style, indicating ACM was used as a marker of ethnicity. There may be a dominant ACM style by region where sites share similar material culture.</td><td>EXPECTATION MOSTLY NOT MET</td></tr>
<tr><td>Formative Period: Dominant ACM styles by region but not site.</td><td>EXPECTATION NOT MET

(ACM styles differ by site, suggesting a different ethnic differentiation, or ACM served an alternative purpose).</td></tr>
<tr><td>Regional Development Period: Dominant ACM styles by site but not region.</td><td>EXPECTATION NOT MET

(ACM styles similar by site, suggesting a possible regional ethnic differentiation or ACM served an alternative purpose.)</td></tr>
<tr><td>Late Period: Dominant ACM styles by region but not site.</td><td>EXPECTATION MET</td></tr>
</table>

It is also important to note that while the beginning of this study utilizes multiple ACM typologies, the Level 2 and 3 typologies were abandoned due to low cell counts that produced statistically weakened results. This study demonstrates that the simpler typologies are best suited for this type of analysis. The remaining typologies are still important for scrutinizing the data for determining the social motivations of ACM as they can demonstrate finer details related to the purpose of ACM, even if they do not produce statistically strong results. These typologies may be best reserved for investigations utilizing very large samples or different methods for interpreting the data.

5.5 Conclusion

The purpose of this study was to determine if ACM was a marker of social status (de las Casas, 1892 [1561]; Torquemada, 1995 [1557-1664]) or ethnicity (Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; de la Vega, 1966 [1609]) among northern Chilean groups. A systematic study of a large data set from this region was undertaken through examinations of grave goods for the Regional Development Period and geographical distributions of ACM styles for each period. After this analysis, the results do not support the ethnicity hypothesis . An exception is made for data from the Late Period as these data do support the ethnicity hypothesis. The social status hypothesis can only be partially rejected since only one period, the Regional Development Period, was studied, but these results do not support the hypothesis of ACM as a marker of social status. Overall, alternative explanations for the cultural motivations of ACM may be more probable, but it is beyond the scope of this investigation to test these alternative hypotheses. These results demonstrate the need for scholars to be cautious in assuming that the dominant paradigm about lowland and highland ACM styles are applicable to all regions in the Andes since both this study and the early literature demonstrate that this was not always the case.

Based on the results of this study, several typologies could be used for this type of analysis, and it would be up to the discretion of the practitioner to decide which would be best. In the case of the grave good analysis, the exploratory analysis using modification presence or absence showed no difference in energy expenditures between the two cranial forms, and subsequent analyses with the various expanded typologies found less and less difference. In the future, such a result at the first, exploratory step could indicate that no further study is necessary and the following steps could be skipped if preferred or possible. In the case of this study, these additional steps could not be skipped as Hypothesis 1b required an examination of individual ACM styles to determine if a difference in energy expenditures existed among them, but if the purpose of the study does not require a refinement of the data, then these steps can be skipped.

For the ACM style distribution analysis, it appears that the Level 1 typology is best for this type of analysis as it demonstrates the highest incidence of styles since the data are not heavily atomized. The Level 2 typology is also useful in this type of analysis. The results do demonstrate a definitive preference in one style variant over another, and further atomization of the ACM styles does not appear to be necessary. The use of this typology would be beneficial in cases where discerning style variability is necessary or beneficial. The Level 3 typology produces too many results that are too atomized and produce statistically weakened results due to low cell counts in the data table. Overall, the results of the Level 3 typology are too confusing and do not aid in this type of analysis but may be useful in cases where the data sets are very large ($n > 1000$).

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Chapter 6

6 Conclusion

The purpose of this study was test to hypotheses regarding the practice of ACM in northern Chilean pre-Columbian populations, specifically focusing on determining A) the effects of ACM on epigenetic traits and facial metrics to determine whether modified crania can be used in biodistance studies, B) if and to what extent ACM may have increased morbidity and mortality in modified individuals, and C) the cultural motivations of the practice in the northern Chilean region. This study explored three hypotheses: 1) ACM did not affect epigenetic trait incidence or facial dimensions, 2) ACM increased the morbidity and mortality of those whose crania were modified, and 3) ACM was a marker of a social status among northern Chilean populations despite societal changes over time. The objective of testing of these hypotheses was to deepen the current cultural and biological understanding of the practice of ACM. The hypotheses were tested with complementary methods which included quantitative (e.g. cephalometric and statistical) and qualitative (e.g. epigenetic trait and pathological conditions scorings, grave good analyses) methods.

Chapter 1, "Introduction," introduced the general context of this doctoral research and outlined the primary hypotheses explored within the dissertation. Chapter 2, "Literature Review: ACM and Typology," provided a comprehensive literature review concerning the study of ACM, covering the cross-cultural motivations of practicing ACM, studies focusing on the effects of ACM on epigenetic traits and facial metrics, and typological designations of ACM styles, in order to determine if and how the use of the various typologies employed in ACM studies affected the results of each study. This chapter also described the "nested typology method," a method that utilizes several different typologies, ranging from simplistic to expanded. The purpose of this "nested typology" is to allow for easy comparison of results among past and present studies, as well as provide information concerning which typology is best suited for the study of the population.

Chapter 3, "Examining the Effects of Artificial Cranial Modification on Craniofacial Epigenetic Traits and Facial Metrics", inspected the biological consequences of ACM in relation to epigenetic traits and facial metrics. Epigenetic traits and facial metrics related to facial and cranial growth were examined as they are used to determine biological relatedness and affinities in populations. There remains disagreement among scholars regarding if and to what degree ACM affects epigenetic trait incidence and facial bone growth and how one may be able to control for such effects. This debate is particularly relevant to northern Chilean populations because several studies have used these methods to determine biological affinities in these groups. As well, some of these studies did not control for the effects of ACM on these traits. If ACM was found to affect these traits, this would contribute to the existing literature and directly affect the previous interpretations about biological affinities in northern Chile.

Chapter 3 presented the results of several methods that were employed to test the hypotheses that ACM would not affect the incidence of epigenetic traits or facial measurements among these groups. Epigenetic trait incidences were statistically tested between modified and unmodified individuals, and facial measurements between the two groups were examined using cephalometric analyses and other statistical tests (e.g. ANOVA, Student's T-test). Upon the completion of these analyses, it was concluded that ACM does not significantly or systematically affect either epigenetic traits or facial measurements when ACM styles are lumped together. Separation of ACM styles into the Level 1 styles demonstrated differences in epigenetic traits and facial measurements related to each style. Thus, the lack of significant differences between the unmodified group and the ACM styles combined is actually the product of increased variability (statistical noise) in the combined group, caused by the different forces acting on the cranium by the appliances used to produce each style.

Chapter 4, "Love You to Death: An Investigation of Artificial Cranial Modification, Morbidity, and Mortality", examined the biological consequences of ACM as they relate to increased morbidity and mortality in modified individuals as compared to their unmodified counterparts. Two recent studies (Guillen *et al.*, 2009; Mendoca *et al.*, 2008) presented evidence of the premature deaths of several infants that they attributed to ACM as ACM related consequences to health, a claim previously asserted by Diez de San Miguel (1964 [1567]). These studies called into question the presumed safe use of this practice, which had been largely taken for granted in the literature. The purpose of this study was to test the effects of ACM on the health of modified individuals to see if the cases identified by Guillen *et al.*, (2009) and Mendoca *et al.* (2008) were isolated or more common than originally thought.

A suite of pathological conditions associated with ACM were statistically tested between modified and unmodified individuals. The purpose of this examination was to investigate the relative health and to gauge if unmodified individuals appeared to be healthier compared to their modified counterparts. As well, additional examinations were conducted to determine if any one ACM style increased morbidity and mortality versus the others. The results determined that there was sufficient evidence to support the hypothesis that ACM, regardless of modification style, could lead to increased morbidity and mortality in these populations.

Chapter 5, "Changing Identities: A Reanalysis of the Social Motivations of Artificial Cranial Modification Among Northern Chilean Populations", investigated the cultural motivations of ACM in northern Chilean groups over an extended temporal span (approximately 3000 years). There exists a debate in both the ethnohistoric and bioarcheological literature concerning the use of ACM among past Andean populations, particularly among northern Chilean groups. Several scholars cite both ethnohistoric and bioarchaeological literature claiming that ACM was used as a marker of ethnicity (e.g. Blom, 1999 & 2005b; Blom *et al.*, 1998; Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; de la Vega, 1966 [1609]; Dingwall, 1931; Hoshower *et al.*, 1995; Hrdlička, 1912; Stewart, 1943; Torres-Rouff, 2002 & 2003; von Tschudi, 1846; Weiss, 1961), but a number of ethnohistorical and bioarchaeological studies exist that contradict this assertion, instead claiming ACM was a marker of social status (e.g. Boadas-Rivas, 1995; Cassman, 1997 & 2000; de las Casas, 1892 [1561]; Doutriaux, 2004; Sutter, 2005;

Torquemada, 1995 [1557-1664]). This debate has been revitalized among northern Chilean scholars where several bioarchaeological studies employing different methods and types of data have reached conflicting conclusions regarding the use of ACM. A resolution to the debate concerning the cultural motivations of ACM within northern Chile could clarify the use of ACM within the general Andean context. Another aspect of this study, the use of multiple, distinct time periods with varying levels of societal complexity, made it possible to examine if the cultural motivations for practicing ACM changed over time.

Investigations utilizing ACM styles compared to location (by general regional and specific site designation) and grave good quantity and quality were tested in order to determine if ACM was used as a marker social status or if it was instead used as a marker of ethnicity. The results of this investigation could not narrow the purpose of ACM to either of these motivations but instead suggest that there may have been multiple motivations for the practice of ACM among these groups. This conclusion weakly links ACM to a marker of ethnicity but further research is necessary since other motivations, such as its use a marker of sex, ferocity, protection, etc. (Cieza de Leon, 1984 [1553]; Cobo, 1979 [1653]; Dingwall, 1931; Fernandez de Piedrahita, 1881; Morton, 1839; Torquemada, 1995 [1557-1664]; Weiss, 1961), may also be responsible for this practice among northern Chilean groups and could account for the ACM style trends noted among these groups.

The conclusions reached by all of these studies demonstrate that our current knowledge of ACM is limited and that further study is necessary. A universal explanation for the practice of ACM in the Andes may be unreachable, particularly when different groups, regions, and periods are lumped together. The same applies to the biological consequences of ACM and the conflicting results in the current literature now coupled with the results of this study. The results of this study show that neither the purpose of ACM nor its biological consequences were fixed, and each population by geographic region and period must be analyzed with that in mind.

6.1 Future Studies

Some of the results offered here help to resolve the current debates regarding ACM and its effects on the Precolumbian Chilean people and on modern analytical techniques. It is clear, however, that further research among northern Chilean and other populations is required to further clarify the debates. As well, the results of these studies have also led to new and interesting questions which remain to be answered.

Regarding the biological consequences of ACM and biological affinities, further study into alternative methods to determine biological relatedness among modified and unmodified individuals should be undertaken in order to control for the effects of modification. It would be beneficial if such methods could be generalizable so that they could be applied to other cultural groups elsewhere in the world. This approach would aid in cross-cultural comparisons but may be difficult to complete since genetic differences vary greatly among geographically distant or proximate groups. This difficulty should not be a hindrance in attempting to create this method as the benefits would be numerous.

While this study did show evidence that modification may have increased mortality among juveniles, it remains unclear if ACM affected health over the entire lifetime of an individual. An examination of ages at death of modified and unmodified adults within the sample may garner information that shows whether ACM shortened the lifespan of modified individuals. Further investigation into this matter is necessary, particularly since so much emphasis has been placed on the increased mortality of infants and juveniles, rather than adults. If ACM did shorten the overall lifespan of modified individuals, this evidence would reveal previously unidentified chronic effects of ACM and support, albeit in a new way, the hypothesis that ACM did increase morbidity and mortality. Additionally, an examination of the postcranial remains of the juveniles surveyed in this study is necessary in order to further scrutinize the source of the cranial lesions. This investigation could rule out causes such as anemia, scurvy, infections, etc.

as the source of the cranial lesions associated with ACM since on their own the cranial lesions are non-specific and could be caused by several pathological conditions.

Regarding the cultural motivations of ACM, the results of this investigation have added yet another dimension to the understanding of ACM in the past. The ethnohistoric literature reports that ACM was used for a variety of reasons among Andean groups (including social class, sex, prevention of attack from evil spirits, improvement of health and work ethic, and an appearance of ferocity in battle), but the bioarchaeological investigations have consistently reported ACM used as either ethnicity or social status. While the results of this study primarily support one motivation, they do so weakly, casting doubt on the general conclusion. It appears that ACM reflected a different kind of identity, such as those recognized in the ethnohistoric literature, or was an expression of a different kind of identity in addition to ethnicity or social status. These ideas have not been previously put forward and require further study as these could explain some of the discrepancy in conclusions currently in the literature.

There are several ways in which to further evaluate the suggestion that ACM was a marker of individual identity. The first is to reexamine the material culture evidence in northern Chile. Scholars have previously attributed several types of material culture (e.g. pottery, textiles, technology) to markers of ethnicity, but this investigation failed to support the use of some of these items as ethnic identity markers based on the criteria of ethnicity as presented in the literature and utilized in this dissertation. A critical evaluation of textile evidence from the Regional Development Period by Cassman (1997 & 2000) demonstrated that textiles were more indicative of social status than ethnicity as previously assumed by the ethnohistoric evidence. This contradiction suggests that further evaluation of the material culture evidence in the region is necessary in order to refine what, if any, social identities were being conveyed through them.

Isotopic investigations of identity could also be beneficial. Isotopic studies focusing on the migratory and dietary patterns of individuals would provide data that could be compared to ACM style to see if particular relationships exist which demonstrate ethnicity, social status, or other identities. If there are trends of specific ACM styles being consistently found with migratory or foreign individuals, this could be indicative of ACM as a marker of ethnicity and support hypotheses related to highland migrations to the region. As well, dietary trends as related to ACM styles could demonstrate ethnic, social status or other identity differences. This information would further our understanding of ACM among these past groups.

Future studies of ACM types and distributions in other culturally distinct groups who were in contact with northern Chilean group (e.g. Tiwanaku and Moquegua Valley groups) should also be conducted. ACM trends in these groups should be compared and contrasted with the results from the northern Chilean groups in order to either further support or refute the conclusions reached in this study. This investigation would be particularly beneficial since more contextual information (e.g. material culture evidence, mortuary and residential information, etc.) is available for these groups than in northern Chile, adding strength to the interpretations that would be derived from the study of these groups. Some previous studies of ACM trends in groups have already been conducted (cf., Blom *et al*., 1998; Blom, 1999, 2005a, 2005b; Hoshower *et al*., 1998), but the methods were different, making it difficult to compare results.

Additional studies on traumatic lesions related to violence, post-cranial epigenetic trait incidences, and aDNA on individuals in these groups should be conducted in order to further test the hypotheses regarding the cultural motivations of ACM. Trends in these data as compared to ACM are additional means of testing the cultural motivations of ACM. They were not addressed in this study due to lack of material and means at the time of data collection, but they should be addressed in future research to add further information to this research area.

The current literature is full of different conclusions, demonstrating that one should be careful about generalizing from one study to the next. The results of this study are specific to groups of the northern Chile, but the questions raised and the methods used are generalizable to other regions. Differences in genetic compositions of samples, degrees of cranial modification, social complexity, etc. are all confounding factors that have affected the outcomes and interpretations of previous studies. Furthermore, this study has highlighted the danger of making simplistic assumptions about the cultural function of ACM. While the primary purpose of this study was to clarify the debates in the literature that focuses on northern Chile, it has yielded many conclusions, and the results show that our understanding of ACM is currently incomplete. There have been several new questions and areas of research pertaining to identity expression and biological consequences of ACM broached. The pursuit of these new questions will hopefully clarify the current debates concerning ACM and further our current understanding of the practice.

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"Skeletal Analysis of the Zimmer Collection." KEWA, Ontario Archaeology Society, London Chapter. October 2007; Issue 6: 2-8.

Book Review:

Thinking About Cultural Resource Management: Essays from the Edge submitted to "The Canadian Journal of Native Studies," Volume XXV, Number 2, pages 628-629; published November 2005.

Natives and Settlers Now and Then: Historical Issues and Current Perspective on Treaties and Land Claims in Canada.
And *Sacred Claims: Repatriation and Living Tradition,* dual book review, submitted to H-Amerindian, Academic Listserve; published.

Encyclopedia Entries:

"Chinchorro Culture." 2009. In *Encyclopedia of World History.* Santa Barbara, California: ABC-CLIO, Inc.

"Eridu." 2009. In *Encyclopedia of World History.* Santa Barbara, California: ABC-CLIO, Inc.

"Monte Verde." 2009. In *Encyclopedia of World History.* Santa Barbara, California: ABC-CLIO, Inc.

"Hopewell Culture." 2008. In *Encyclopedia of American Indian History.* Santa Barbara, California: ABC-CLIO, Inc.

Other:

"Don't Forget Your Snickers Bar, and Other Helpful Tips to Know Before Embarking on Fieldwork." Winter 2011. CAPA Newsletter.

"Message from the CAPA Student Representative." Winter 2011. CAPA Newsletter.

"Every Little Bit Helps: Seeking Out Additional Sources of Research Funding." Fall 2010. CAPA Newsletter.

"15 Tips on Getting into Graduate School." Fall 2010. CAPA Newsletter.

"Message from the CAPA Student Representative." Fall 2010. CAPA Newsletter.

"Raising Public Awareness." Winter 2010. CAPA Newsletter.

"10 Ways to Promote Public Awareness." Winter 2010. CAPA Newsletter.

"Message from the CAPA Student Representative." Winter 2010. CAPA Newsletter.

"Message from the CAPA Student Representative." Fall 2009. CAPA Newsletter.

"Growth and Development and Paleopathological Analysis of Ancient Northern Chilean Populations as Related to Possible Arsenic Poisoning." 2007. Masters Thesis, University of Western Ontario, London, Ontario.

"Skeletal Inventory of Huaca Santa Clara Collection." 2007. Manuscript on file. Virú Polity Project, London, Ontario.

6. **CONFERENCES (Primary Author)**

2012 — *Love You to Death: An Exploration of Artificial Cranial Modification, Morbidity, and Mortality*, Podium Presentation, Western Research Forum, University of Western Ontario, London, Ontario

2011 — *The Costs of Fitting In: Body Modification, Identity Communication, and Health*, Podium Presentation, Western Research Forum, University of Western Ontario, London, ON

Reshaping Life/Death: Exploring the Link Between Artificial Cranial Modification and Morbidity and Mortality among Ancient Northern Chilean Groups, Podium Presentation, Canadian Association of Physical Anthropology Annual Meeting, University of Montreal, Montreal, QC

Bioarchaeology in the Andes and South America, Symposium Organizer, Canadian Association of Physical Anthropology Annual Meeting, University of Montreal, Montreal, QC

2010 — *Fitting In or Standing Out?: Examination Cultural Motivations for Artificial Cranial Modification in Northern Chile*, Podium Presentation, Midwest Andean and Amazonian Archaeology and Ethnohistory Conference, University of Indiana-Purdue, Fort Wayne, Indiana

The Great Identity Debate: Examining the Purpose of Artificial Cranial Modification in Northern Chile, Podium Presentation, Western Research Forum, University of Western Ontario, London, ON

2009	*Facial Growth Changes as Related to Artificial Cranial Modification*, coauthors Drs. Lesley Short and Andrew Nelson, Gerald Conlogue, Poster Presentation, Western Research Forum, University of Western Ontario, London, ON
	Growing Pains: Examining the Effects of Artificial Cranial Modification on Cranio-Facial Growth, Podium Presentation, Midwest Andean and Amazonian Archaeology and Ethnohistory Conference, University of Michigan, Ann Arbor, Michigan
	The Effects of Arsenic Exposure on Biological Growth in Pre-Hispanic Individuals from Northern Chile, coauthor Dr. Bernardo Arriaza, Poster Presentation, Society for American Archaeology Annual Meeting, Atlanta, Georgia
2008	*Methodological Considerations of Llama Sacrifice at Huaca Santa Clara*, Podium Presentation, Western Research Forum, The University of Western Ontario, London, ON
	Changes in the Growth and Development of the Face as Related to Artificial Cranial Modification: A Cephalometric Analysis, coauthors Drs. Lesley Short and Andrew Nelson, Gerald Conlogue, Poster Presentation, Canadian Association of Physical Anthropology Annual Meeting, Hamilton, ON
2007	*Mortuary Context of Maya Subadult Burials of the Barton Ramie, San Jose, and Uaxactun Sites in Mesoamerica*, Podium Presentation, Anthropology, Physical Anthropology, Linguistics and Archaeology (APALA) Student Conference, University of Manitoba, Winnipeg, Manitoba
	Childhood Health and Morbidity in Ancient Chilean Cultural Groups: A Preagricultural vs. Agricultural Comparison, coauthor Dr. Bernardo Arriaza, Podium Presentation, 35th Annual Midwest Conference on Andean and Amazonian Archaeology and Ethnohistory, Southern Illinois University, Carbondale, IL
	The Effects of Inorganic Arsenic on Human Populations: An Ancient and Modern Day Perspective on Northern Chilean Populations, coauthors Drs. Marvin Allison and Bernardo Arriaza, Podium Presentation, Disease in Global Environmental History Conference, York University, Toronto, ON

A Northern Chilean Perspective on Preagricultural and Agricultural Health: Preliminary Research with Child Morbidity Patterns, Podium Presentation, UWO Anthropology Society Symposium, The University of Western Ontario, London, ON

Arsenic and Its Connection to Mummification, Podium Presentation, Western Research Forum, The University of Western Ontario, London, ON

Penetrating Questions on Llama and Child Sacrifice Patterns at Huaca Santa Clara, Podium Presentation, 26th Annual Northeast Conference on Andean Archaeology and Ethnohistory, Ithaca College, Ithaca, NY

2006 *Arsenic and Mummification: An Exploration of the Connection Between the Causes of Mummification and Possible Arsenic Poisoning*, Podium Presentation, Canadian Association of Physical Anthropology (CAPA), Trent University, Peterborough, ON

2005 *Analysis of the Skeletal Remains of the Emmons Site, Fulton County, IL*, Poster Presentation, Undergraduate Research Academy Symposium, SIUE, Edwardsville, IL.

7. **CONFERENCE PRESENTATIONS (Co-author)**

2008 *Arséniasis: Estudio de Esqueletos, Momias y Medio Ambiente de Arica,* authors Drs. Bernardo Arriaza, Hugo Lienqueo, Lorena Cornejo, Dula Amarasiriwardena, Vivien Standen, and Christine Boston, Poster Presentation, XXVII Jornadas Chilenas de Salud Pública, Santiago, Chile.

8. **PUBLIC LECTURES**

2012 *Conforming to Society: A Brief but Comprehensive Review of Artificial Cranial Modification*, Skeletal Biology Course, Department of Anthropology, University of Western Ontario, London, Ontario

Topics in Andean Bioarchaeology: Case Study into the Pros and Cons of the Use of Museum Collections, Andean Prehistory Course, Department of Anthropology, University of Western Ontario, London, Ontario

2011 *My Story of My Quest for My Ph.D.* Brown Bag/Western Anthropology Graduate Society Seminar, Department of Anthropology, University of Western Ontario, London, ON

2010 *Racing to the Finish: Tips on Successfully Completing Your Thesis*, Brown Bag Seminar, Department of Anthropology, University of Western Ontario, London, ON

2009 *Changes in Craniofacial Growth as Related to Artificial Cranial Modification,* Brown Bag Seminar, Department of Anthropology, University of Western Ontario, London, ON

Artificial Cranial Modification and Growth: Connections and Relationships, Ontario Archaeology Society Meeting, London Chapter Meeting, London, ON

2008 *Analysis of Skeletal Remains from the Zimmer Site*, Ontario Archaeology Society Meeting, London Chapter Meeting, London, ON

Reshaping Lives and Predetermining Destiny: Behind Cultural and Biological Factors of Artificial Cranial Modification. Schulich School of Dentistry, University of Western Ontario, London, ON

2007 *Los Chinchorros*, *Arsenic, and the World's Oldest Mummies*, Ontario Archaeology Society, London Chapter Meeting, London, ON

2006 *The Effects of Arsenic on Ancient Chilean Populations: Preliminary Report,* Brown Bag Seminar, Department of Anthropology, University of Western Ontario, London, ON

9. RESEARCH FUNDING

2010 Graduate Thesis Research Award
Awarded $750 in support of Doctoral Research.

2009 Ontario Graduate Scholarship
Awarded $15000 in support of Doctoral research. Award duration for three academic terms.

GTA Union Scholarship
Awarded $1000 in support of Doctoral research.

2008 GTA Union Scholarship
Awarded $1000 in support of Doctoral research.

Graduate Thesis Research Award
Awarded $750 in support of Doctoral research.

2006 Graduate Thesis Research Award
Awarded $750 in support of Masters research.

2004-2005 Undergraduate Research Academy (URA)
Proposal: "Analysis of the Skeletal Remains of the Emmons Site, Fulton County, IL."
A $500 grant awarded in order to study skeletal remains of a Native American population that inhabited the Illinois River Valley.